Improvement of Forest Trees

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IMPROVEMENT OF FOREST TREES

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FORESTRY is a young profession. In comparison to agriculture, it has just been born. Under pressure of necessity, farmers were breeding crop plants long before genetics supplied the key to many of the mysteries they encountered; but the natural products of the forest were plentiful and were taken as needed, without thought of artificial replacement. Until very recently, indeed, even foresters have been

Figure 1.—A "man-made forest" of slash pine in southeastern Louisiana. The artificial regeneration of cut-over lands on such a large scale emphasizes the need for guidance from sound genetics work in the improvement of forest trees.

content to utilize wild trees as they were found. This lack of interest in the improvement of forest trees has been due both to the lower unit value of the stock and to the greater difficulties involved in breeding work.

Various factors have been responsible for a gradual change in attitude within recent years. The rapid recession of the timber supply accessible to established wood-using industries; the inferior quality

of much of the second-growth wood; more stringent quality requirements in the finished product to meet the competition of other manufacturers or of substitute products, necessitating uniformity or improvement in quality of the raw wood material; the denudation of forest areas by uncontrolled commercial exploitation and the necessity for having them restocked and managed by public agencies in the public interest (fig. 1); the urgency of soil conservation on nonagricultural lands—all these have played a part in exerting pressure for a more intelligent attitude toward the forest problem as a whole, and the exploration of any possibilities that might be promising.

The tree breeder, then, has just begun to roll up his sleeves. In comparison with his confreres who deal with the older agricultural crops, his attitude is one of humility; he is only at the beginning and he has much to learn. But on the other hand, because his work is all before him, he sees infinite possibilities ahead for the improvement of forest trees by breeding and selection.

This should be kept in mind by the reader as he peruses the following brief account of the present status of breeding work with forest trees. In various parts of the world, considerable necessary spadework has been and is being done. Much of it might not be called either genetics or breeding by those who have become facile in dealing with the smaller, quicker maturing crop plants. Nevertheless, this spadework will be of great value to forest-tree improvement, and it is essential to the building up of a science of forest genetics. The appendix gives a concise summary of most of the work relating to forest-

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UNTIL *very recently, foresters have been content to utilize wild trees as they were found. There has been a gradual change in viewpoint, brought about by the same factors that have exerted pressure for a more intelligent attitude on the part of the public toward the forest problem as a whole—the depletion of the timber supply accessible to established wood-working industries; the inferior quality of much of the second-growth wood; more stringent quality requirements in the finished product; the denudation of forest areas by uncontrolled commercial exploitation; the urgency of soil conservation on nonagricultural land. Today foresters are eager to explore any possibilities that might be promising, and tree breeding seems to be one of the most promising. In comparison with the breeder of the older agricultural crops, the tree breeder has just begun; his attitude is one of humility; but because his work is all before him, he sees infinite possibilities ahead. In various parts of the world much necessary spadework is now being done to lay the foundations of a true science of forest genetics.*

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tree breeding now being carried on by public and private agencies in the United States, and some of the work being done in foreign countries.

The improvement of any wild stock should logically begin with (1) a segregation of varieties, races, and strains of the wild population. It should then proceed to (2) the evaluation of the characteristics of each group, (3) the selection of the best individuals in each of the best strains, (4) breeding and selection, which controls both parents and utilizes the best germ plasm available in these wild stocks, and, finally, (5) the production of decidedly new types by hybridization and by advantageous use of induced or natural changes in the normal number of chromosomes (polyploidy). The improvement of forest trees strictly along these lines would require extensive investigation and planting over many years. Fortunately, all five phases can well be carried on simultaneously.

STUDIES OF SEED ORIGIN—SPECIES, VARIETIES, RACES, STRAINS

For more than 60 years investigators have recognized the importance of seed origin, for which the term "provenience," meaning origin, is often used. The importance of races and strains of forest species first became apparent in Europe, where artificial regeneration of forest stands has been in progress for a much longer period than in the United States. European foresters began to realize that constant and important variations appeared between progenies from seed obtained in different regions. For example, in Sweden, Scotch pine grown from European seed often produced trees of very inferior forest form. Careful study indicated that proper selection of the seed source was necessary for the production of a desirable type of growth and an economically profitable stand. These investigations have led to fairly well controlled seed certification in some parts of Europe.

Forest research stations in the United States (fig. 2) have also been interested in this problem of seed origin (fig. 3) and experimental plantations were started over 20 years ago at several western stations. Test plots established at the Pacific Northwest Forest Experiment Station in 1915, with seed of Douglas fir, have already given valuable data on the existence and characteristics of various strains within this species. Seven apparently superior strains of ponderosa pine have been segregated at the Northern Rocky Mountain Forest Experiment Station from test plots established 23 to 27 years ago. Work at these and other stations is described in the appendix.

The establishment of the Eddy Tree Breeding Station (now the Institute of Forest Genetics, California Forest and Range Experiment Station)[1] in 1925 initiated a project for the intensive study of various problems in forest genetics. Extensive tests at the institute include 100 species and named varieties of pine (the genus *Pinus*) and innumerable climatic forms of many of these species. The seed has

[1] The Eddy Tree Breeding Station was originally founded and financed by James G. Eddy at Placerville, Calif. In 1931, the station was incorporated and deeded to a board of trustees, the name being changed to the Institute of Forest Genetics. Between the years 1931 and 1935 the institute received aid from the Carnegie Institution and the U. S. Department of Agriculture (Bureau of Plant Industry, Soil Conservation Service, and Forest Service). On July 1, 1935, Congress granted funds to carry on work in forest genetics at the California Station and in this year the property of the institute was deeded to the Federal Government and became part of the California Forest and Range Experiment Station.

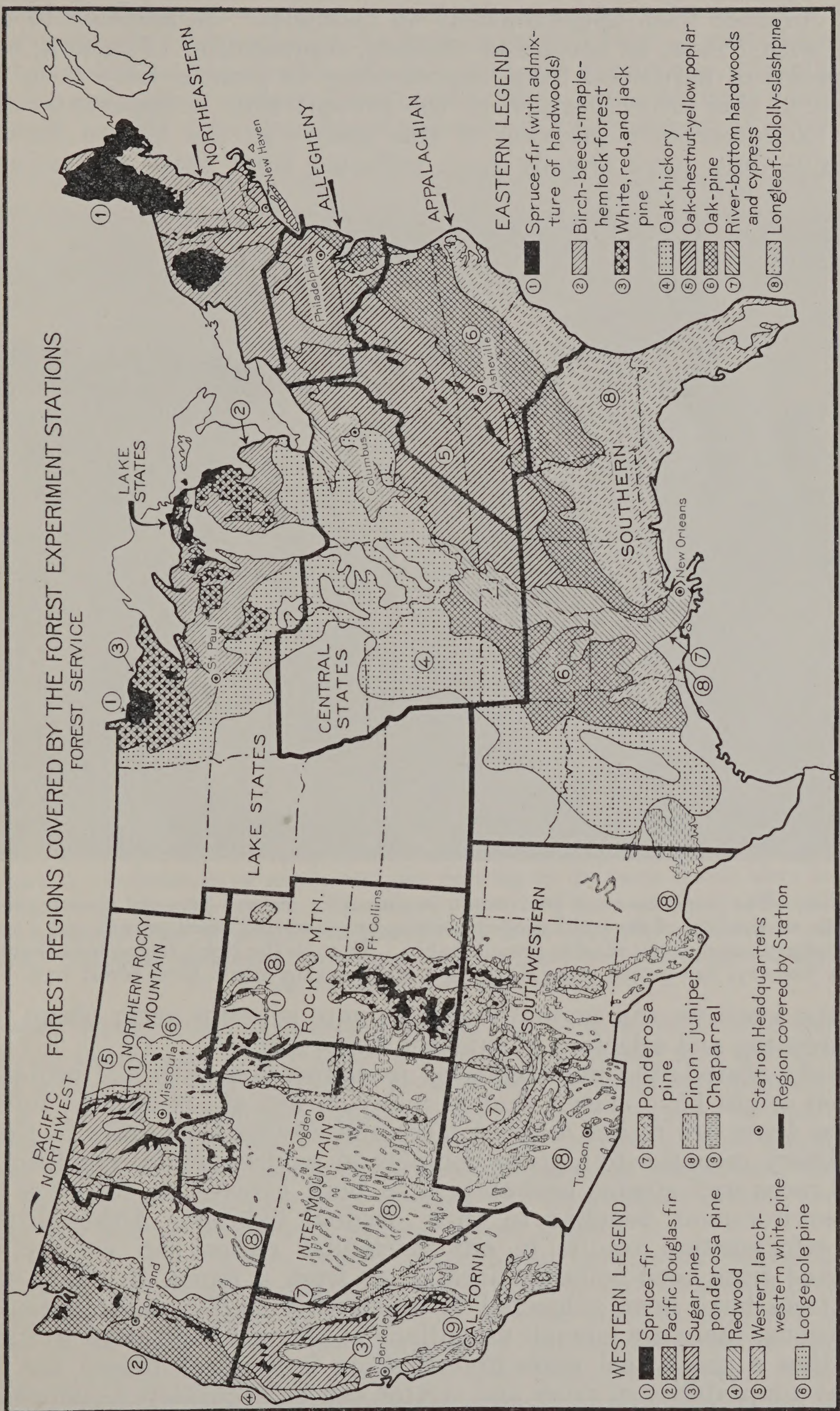

Figure 2.—**Regions covered by the forest experiment stations of the Forest Service and the principal timber types of the regions.**

been obtained from approximately 40 countries. In addition to the work with *Pinus*, 35 species of conifers, representing 17 genera, and 20 species of hardwood trees, representing 13 genera, have been included in this project, which at the present time is apparently the most comprehensive program of this nature in the United States. Valuable data have already been collected from these plantations,

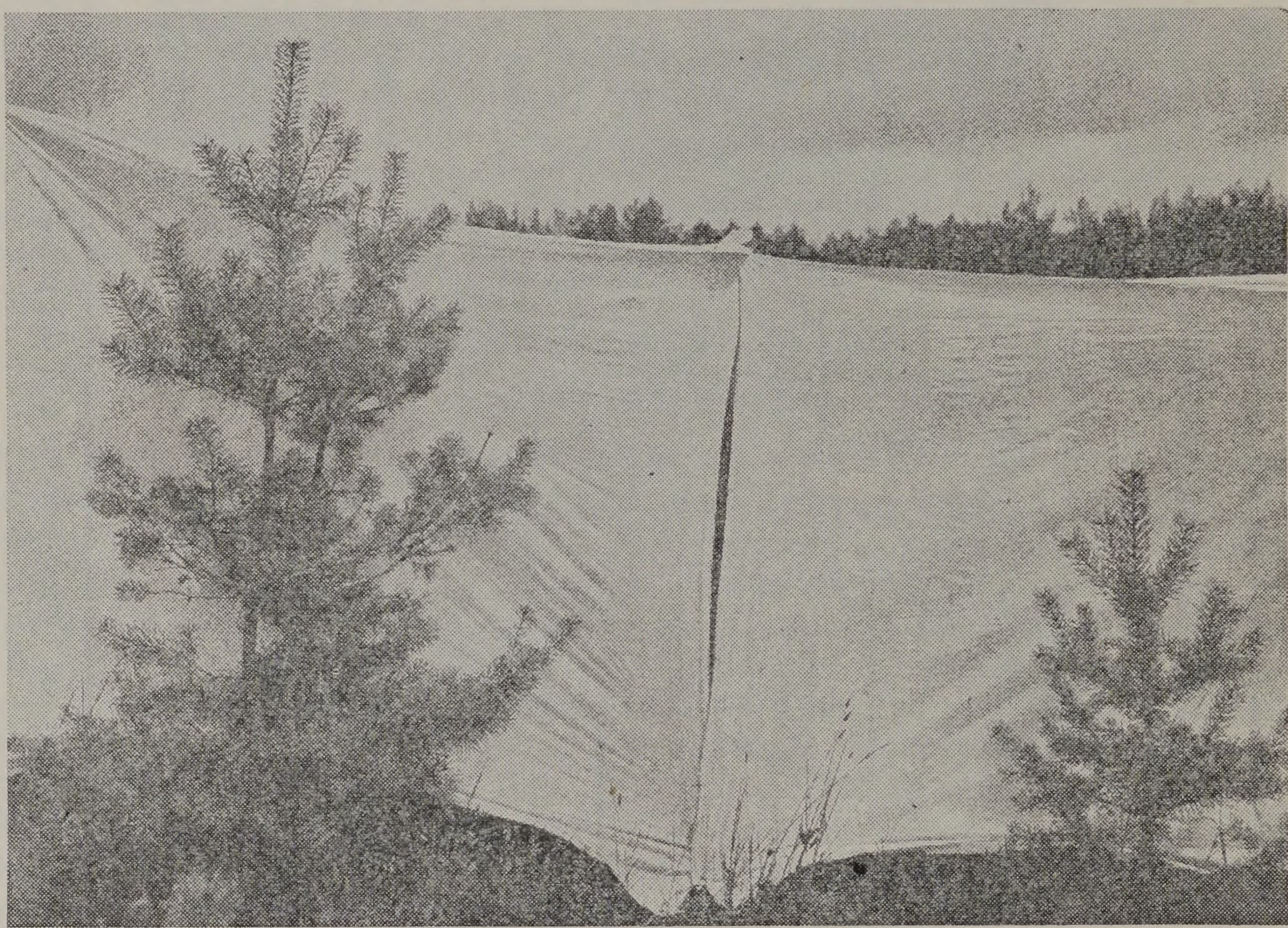

Figure 3.—The importance of seed origin is shown by these 5-year-old Scotch pines. The tree on the left, of central European origin, has inherited rapid growth but a very poor and ultimately unprofitable growth habit. That on the right, from seed collected in Norway, has grown more slowly but will develop into a good forest tree.

and the institute will undoubtedly evaluate superior germ plasm for the breeding and selection of superior forest stocks.

Briefly stated, the investigations in connection with the problem of seed origin have shown that in many, if not all, important forest species there are rather distinct races and strains that differ in their hereditary response to a given complex of environmental conditions. Such races and strains probably have been evolved in response to the environment peculiar to their original habitat. Although the best reforestation results in any particular region can usually be expected from seed collected locally, or from a region in which the seed trees have been subjected to apparently similar environmental conditions, there are enough exceptions to this generalization to indicate that a great deal more investigation is required before the inherent adaptability of races and strains can be accurately cataloged.

INDIVIDUAL SEED-TREE PROGENY TESTS

Individual seed-tree progeny tests resulted from the realization that seed origin was of tremendous importance to the forester in considering

artificial reforestation. Observations that the individuals of the same seed origin showed marked differences in growth habit, in rate of growth, and in resistance to disease, climate, and site conditions, stimulated a further refinement in seed-selection studies. Investigations were soon started on the inherent characteristics of the progeny of individual

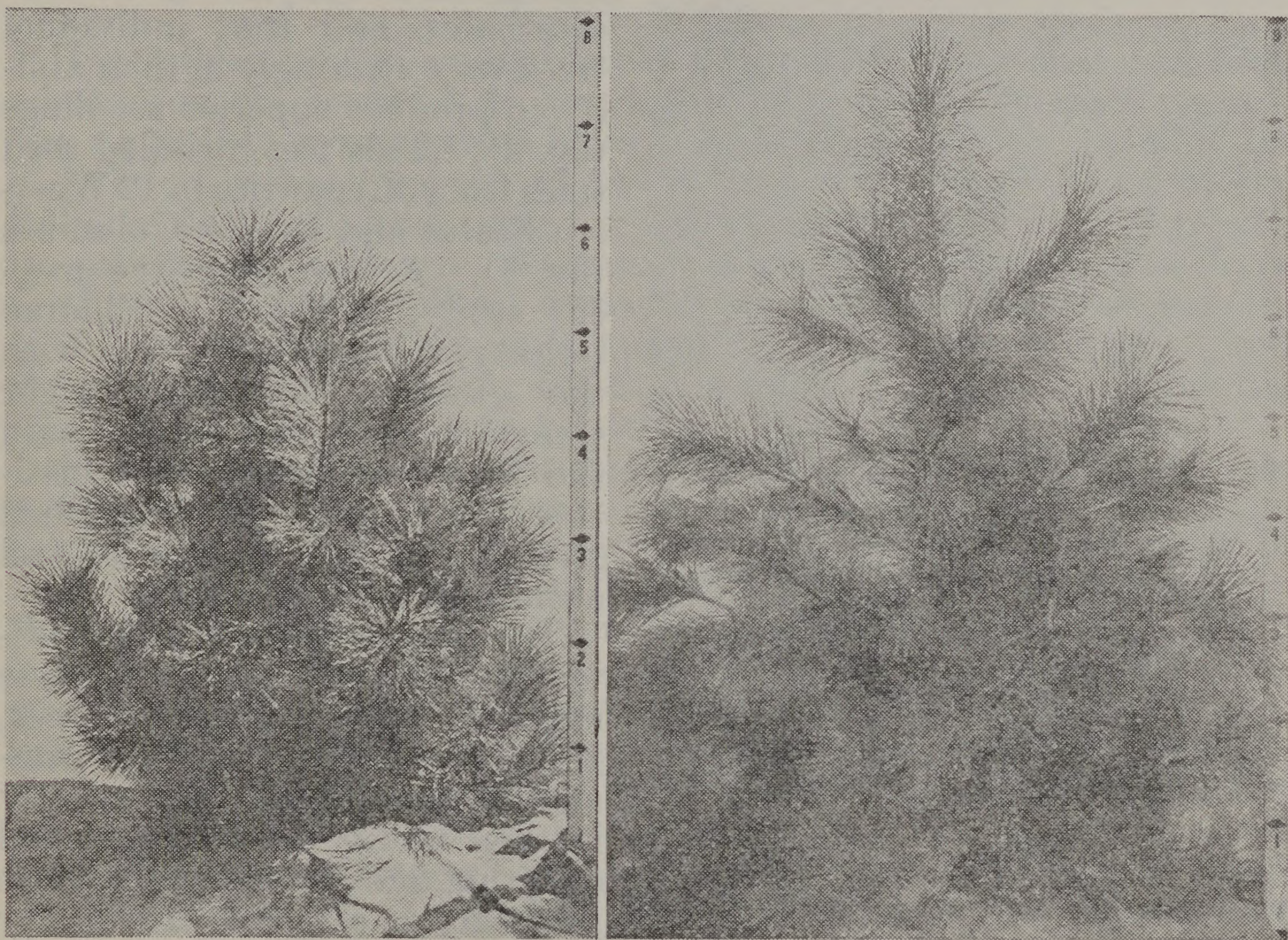

Figure 4.—Individuals of ponderosa pine growing in the same stands show inherent differences in vigor of growth. These two 7-year-old trees are from wind-pollinated seed collected from different seed trees in the same field plot in Eldorado County, Calif. The sister seedlings of both these trees were uniformly more vigorous than those of the slower growing pine of figure 5.

trees. Recognition of only the female parent was involved, since most of the important forest trees are wind-pollinated, and the source of the pollen that had fertilized the seed was necessarily unknown.

A number of European institutions are now engaged in individual seed-tree progeny tests. Oppermann, in Denmark, was among the first to insist on the necessity of carefully selected seed trees. Nicolai of Danzig, in particular, has stressed the importance of this problem and has started work with several forest species.

In the United States, many of the forest experiment stations have included individual seed-tree progeny tests in their research program. The Rocky Mountain Station has located individual trees of the ponderosa pine which are apparently mistletoe-resistant and has begun individual progeny tests with seed from these trees. Mistletoe infection often seriously retards the growth rate in this region and on the poorer sites often results in high mortality. Individual seed-tree progeny tests with green ash at the Lake States Station indicate that there are inherently different climatic races within this species.

An extensive progeny test was started in 1929 at the Institute of Forest Genetics with 742 individual seed trees of *Pinus ponderosa* (ponderosa pine) and its varieties *scopulorum* and *jeffreyi* (Jeffrey pine). Results to date indicate that there are apparently innumerable local strains, each with distinct morphological and physiological characteristics, and that individual trees vary strikingly in their ability to produce superior seedlings (fig. 4). This test included seed trees from 60 counties in 12 Western States and British Columbia (fig. 5). A more intensive progeny study, restricted to Eldorao County, Calif., where types with the greatest hereditary vigor seemed to occur, was started with the 1934 seed crop. The institute is also testing the individual seed progenies of 16 species and natural hybrids of walnut.

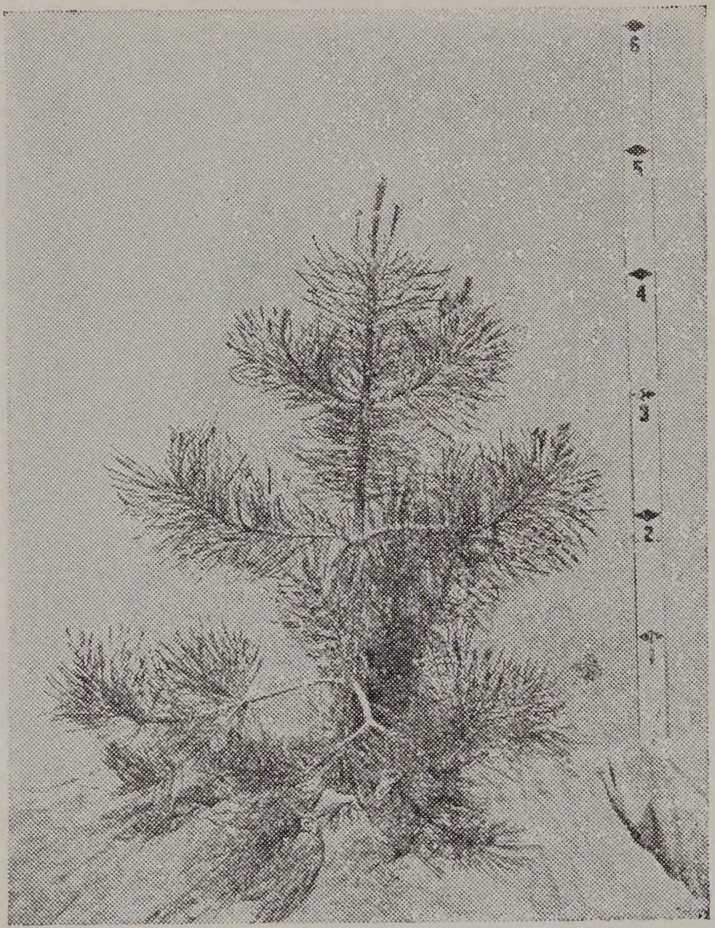

Figure 5.—This tree is typical of the comparatively slow growth of the British Columbia strain of ponderosa pine. Compare it with the more vigorous trees of the same age shown in figure 4. Racial differences are clearly indicated.

The results obtained from individual seed-tree progeny tests indicate that individual trees, growing under the same environmental conditions, vary greatly in their ability to produce good offspring and that it is therefore necessary to establish criteria for the recognition of heritable qualities. Adequate information for the description of good seed trees is not available at present.[2]

HYBRIDIZATION OF FOREST TREES

NUMEROUS natural hybrids have been observed from time to time and the parentage of some of these has probably been accurately ascertained. Among such natural hybrids the following may be noted:

Larix eurolepis [3] (Dunkeld larch) from *L. europaea* × *L. leptolepis*
L. gmelini × *L. Kaempferi.*
Pinus sondereggii from *P. palustris* (longleaf pine) × *P. taeda* (loblolly pine).
P. halepensis × *P. pinaster.*
P. nigra × *P. sylvestris.*
P. montana × *P. sylvestris.*
P. montana × *P. nigra.*
Picea sitchensis × *P. canadensis.*
P. engelmannii × *P. canadensis.*
Salix coerula (cricketbat willow) from *S. alba* × *S. gracilis.*
Ulmus glabra × *U. montana* (Huntingdon elm).
Quercus cerris × *Q. suber* (Lucombe oak).
Royal walnut hybrids (eastern black walnut × various California black walnuts).
Poplar hybrids (Eugenei poplar, Serotina poplar, and others).

[2] Additional information on individual seed-tree progeny tests is included in the appendix.
[3] Species names have too often been applied to hybrids between tree species; in the case of poplars, to hybrid clones existing as a single sex. Hybrids are not species and naming them as such can only lead to confusion.

Many of these hybrids grow more vigorously than either of their parents, and in some instances other valuable properties or characteristics have been noted. For example, the Dunkeld larch is said to be resistant to the larch canker, and the wood of the cricketbat willow is said to be particularly well adapted to the manufacture of cricket bats.

Early Work

If possible, tree breeding should begin with stock that has been selected on the basis of its breeding quality (superior germ plasm), but since 1845 investigators have been interested in the possibilities of hybrids between species of forest trees, primarily because of the fact that species hybrids often surpass their parents in vigor of growth (so-called hybrid vigor). Klotzsch [4] is generally considered to have produced the first artificial hybrids between forest-tree species. In 1845 he hybridized two species each of pine, oak, elm, and alder, and observed that the resulting hybrids possessed growth characteristics superior to their respective parents.

Sporadic attempts to hybridize forest-tree species continued over many years. Ness, working at the Texas Agricultural College, produced a few hybrids between the live oak and the overcup oak in 1909, and a limited amount of breeding appears to have been continued at this station. Henry, working in England, produced several fast-growing poplar hybrids and in 1916 published a paper on the possibilities of obtaining rapid-growing forest stock by hybridization. Since 1916, there have been a number of publications discussing various aspects of the possibilities of hybridizing trees. The loss of our native chestnut through the introduction of the Asiatic chestnut blight stimulated interest in breeding this group, and as a result W. Van Fleet, of the United States Department of Agriculture, carried on breeding work with American and Asiatic chestnut species in an effort to produce an immune or resistant timber type.

Recent Work

The chestnut-breeding work started by Van Fleet has been continued and expanded by the Division of Forest Pathology, Bureau of Plant Industry. Selections have been made from the most promising forest strains of the Chinese hairy chestnut, *Castanea mollissima*, and of forest types of the Japanese chestnut *C. crenata*. First-generation hybrids between Asiatic and American species are usually remarkable in vigor, ordinarily excelling all other hybrids in this respect. Selective breeding has also been directed toward the development of small-sized nuts useful in mast production on trees that might be grown in soils not well adapted to either orchard or forest planting.

The first comprehensive project in hybridization within a tree genus was started in 1924 by the Oxford Paper Co., Rumford, Maine, in cooperation with the New York Botanical Garden, New York, N. Y. The primary purpose of this work was to produce new poplars valuable for pulpwood reforestation (fig. 6). This work has been highly successful. A total of about 13,000 hybrid seedlings was obtained from about 100 different cross combinations between 34 different

[4] See Bibliography, published in the Yearbook separate of this article.

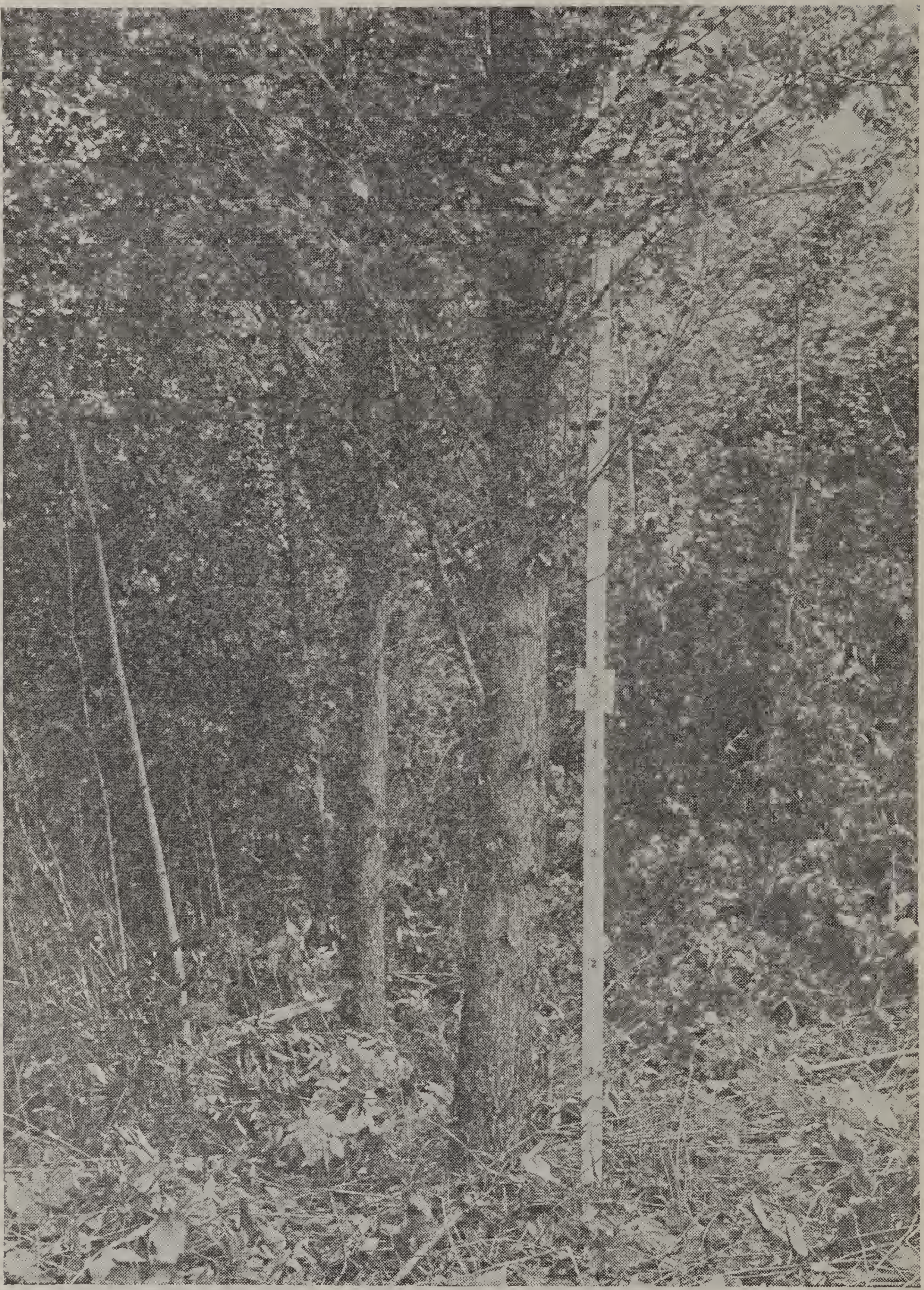

Figure 6.—The Strathglass poplar, one of the selected hybrid poplars produced by the Oxford Paper Co., after 7 years of growth in the field. This tree is approximately 7 inches in diameter and 37 feet tall. It is rather heavily branched, but the branches are small and should offer no difficulties to the use of the wood for soda pulp.

species, varieties, and hybrids of poplars. The parents included 3 white poplars, 5 aspens, 17 black poplars and cottonwoods, and 9 balsam poplars or hybrids belonging in this group. Many of the new hybrids appear especially promising because they surpass the older hybrids, at least during the first 8 years of their life, in rate of growth, resistance to disease and climatic conditions, and habit of growth (fig. 7).

Figure 7.—That well-directed breeding can produce trees immune or highly resistant to tree diseases is demonstrated by these two poplar hybrids. The picture was taken in early September. The trees at the right, without leaves, are members of a clone which is highly susceptible to *Melampsora* rust disease. The trees at the left, in full leaf, are members of a hybrid clone that is much more resistant to this disease. These hybrids are the same age and have the same female parent but different male parents.

Breeding work was undertaken at the Institute of Forest Genetics in 1925 and the institute has now approximately 60 hybrid seedlings involving 8 pine species and varieties as parents.

In 1930 the Brooklyn Botanic Garden, Brooklyn, N. Y., initiated a project for the breeding of chestnut, to produce hybrids that would combine good forest form with immunity to the chestnut blight. Some of the hybrids that have been produced give promise of excellent timber form and resistance to the disease.

The most recent large-scale breeding work was undertaken by the tree crop unit of the Forestry Division, Tennessee Valley Authority, Knoxville, Tenn., to develop trees that will combine good timber qualities with the production of annual crops of fruit (nuts, acorns, berries) of high quality and quantity. Such trees are to be used in tree-crop plantings, where the fruits will produce an annual income and the mature trees can be harvested for lumber or chemical wood.

The work of the Tennessee Valley Authority is of special interest because it aims at an annual income for the forest or wood-lot owner. For example, a stand of oak that will produce a large quantity of acorns will probably more than pay its way to maturity by the hog feed they provide, and if this production can be combined with excellent timber quality, forest planting to prevent soil erosion will

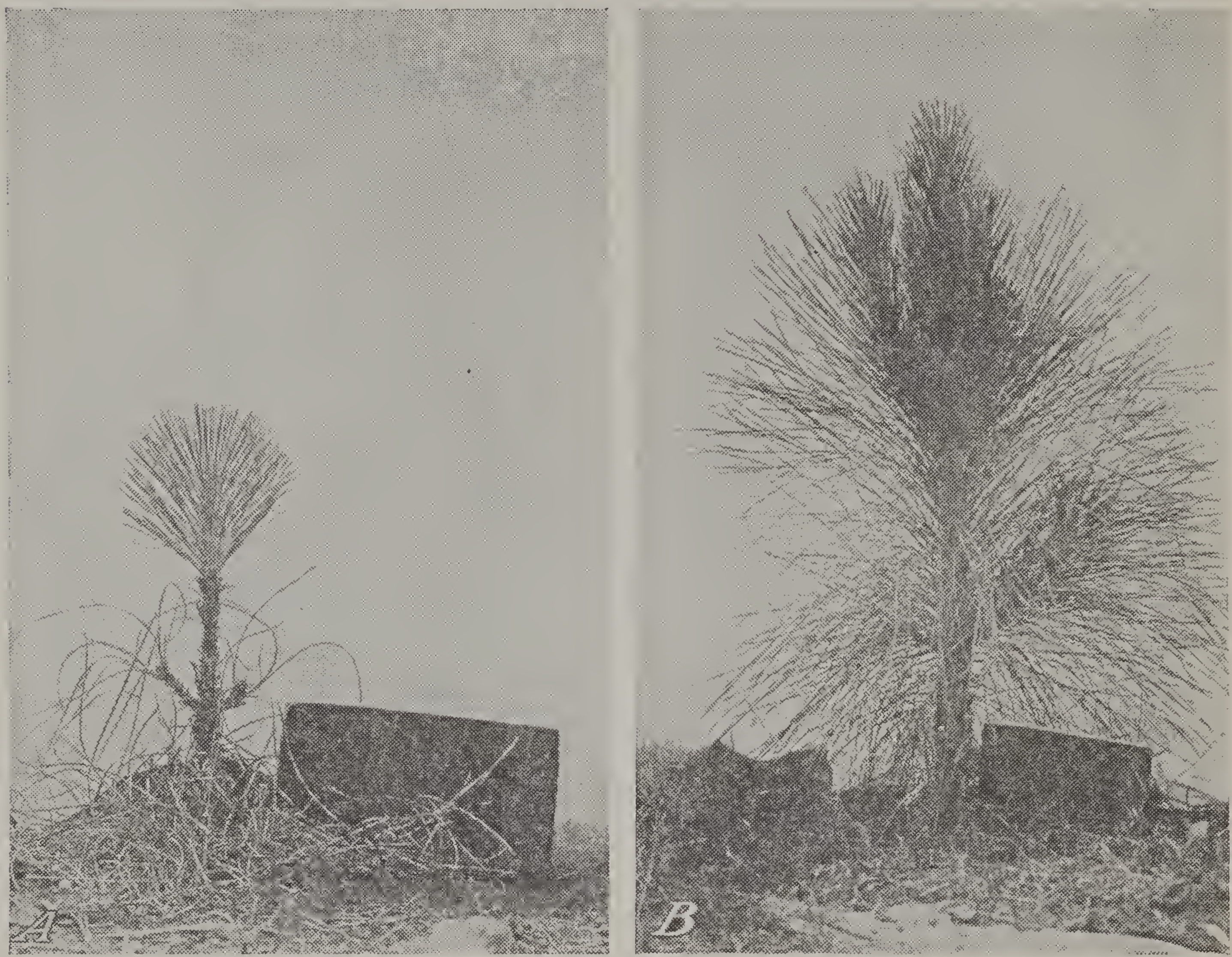

Figure 8.—Artificial hybrids between longleaf and slash pines produced at the Southern Forest Experiment Station show wide variation in susceptibility to brown spot (a needle disease of longleaf pine) in the same plantation: *A*, A 3-year-old hybrid seedling, highly susceptible to brown spot, has lost all of its older needles; *B*, another hybrid of the same age, is relatively free from the disease and shows superior growth and vigor.

be profitable to many southern hill-farmers. Improvement of our best annual-crop trees by hybridization and selective breeding will be essential to the successful and profitable combination of tree crops and forestry on marginal and nonagricultural farm lands.

At the present time the Northeastern Forest Experiment Station, New Haven, Conn., is starting a project in forest genetics directed toward the improvement of forest trees in the Northeastern region. It is expected that the program will include practical and fundamental research on seed origin, progeny tests, selective breeding, and hybridization.

Numerous other investigators in recent years have hybridized species of forest trees to a limited extent. At the Southern Forest Experiment Station, New Orleans, La., hybrid seedlings of *Pinus palustris* $\times$ *P. caribaea* (longleaf and slash pines) were obtained in 1929 (fig. 8), and also hybrids between *P. sondereggeri* (itself a hybrid)

and *P. palustris* and *P. taeda*, respectively. Workers at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., have successfully crossed individuals of a strain of ponderosa pine that is apparently immune to mistletoe. At the Petawawa Forest Experiment station, Petawawa, Ontario, Canada, red spruce and Norway spruce were successfully hybridized in 1932, and in 1936 *Populus canescens* was crossed with *P. tremuloides* in an effort to obtain a hardy aspen hybrid combining the wood characteristics required for match and veneer wood with resistance to heart rot.

Breeding of forest trees is also being stressed in Europe. Larsen, in Denmark, has been carrying on rather extensive breeding studies, especially from the standpoint of self-pollination, and has published his results in some detail. Von Wettstein, in Germany, has been interested in the hybridization of poplars, particularly for the production of trees especially suited to matchwood production. He has developed and described a method for the maturation of hybrid seed in artificial nutrient media. Liese, at Eberswalde, Germany, working with *Pinus montana* (Swiss mountain pine) and *P. sylvestris* (Scotch pine) failed to obtain hybrid seed between these species, which are considered to produce natural hybrids quite frequently. This failure, he concludes, may have been due to lack of "crossibility" between the particular strains used, and the use of other individuals might give positive results.

In addition to these strictly forest species, considerable breeding work has been done with various nut trees, such as the walnut, of which exceedingly vigorous hybrids are now in existence. This work is described in the article on nut-tree breeding elsewhere in this Yearbook.

The outstanding improvement apparent in natural and artificially produced hybrids between forest-tree species amply justifies particular effort in this direction.

VEGETATIVE PROPAGATION

Vegetative propagation will be of great value for the immediate utilization of exceptionally promising natural or artificially produced forest trees. The rapid improvement of horticultural trees has been possible because any new and improved type, hybrid or otherwise, could be immediately multiplied as a clone by grafting, budding, or other forms of vegetative propagation. With forest trees such as the poplars and willows, which can be propagated by cuttings, the tree breeder can utilize exceptional hybrids immediately with the assurance that the individual members of such a vegetative clone will exhibit the same inherent characteristics as the original tree, except for mutations in the body cells of various parts of the tree. These ordinarily occur so rarely that from a practical standpoint they are unimportant. By such methods it is possible to retain any excellent characteristic such as hybrid vigor—the exceptionally rapid growth often inherent in first-generation hybrids—or any new character that is due to an unfixed combination of complementary genes. Few forest trees, however, can be commercially propagated by cuttings, and although many species can be propagated vegetatively by grafting, budding, or layering, these methods are not feasible at present because of their comparatively high cost. It is essential to find cheaper

methods of vegetative propagation if select hybrids or strains are to be multiplied and utilized immediately for forestation planting.

A POSSIBLE APPROACH TO THE IMPROVEMENT PROBLEM

Seed Origin and Individual Seed-Tree Progeny Studies

A search of the literature may leave the impression that investigations in the past have too strongly stressed the subject of seed origin and seed-tree selection, and that the improvement of our forest trees along these lines will be exceedingly slow. But from the standpoint of immediate reforestation requirements, seed-origin and progeny studies are of the greatest importance if the errors responsible for the poor quality of many of the early European plantations are to be avoided. According to Baldwin, approximately 25 percent of the forest stands in Germany are inherently so poorly adapted to their environment that the Government has ordered clear cutting to prevent their regeneration.

A program for the improvement of our forest trees that is concerned with the immediate needs of general forestry may well contemplate studies on seed origin, delineation of races and strains of species and varieties, individual seed-tree progeny studies, and adaptability of exotics on a larger and more intensive scale than in the past. Although such studies are especially necessary to determine the best races or strains for forestation, the data derived from them will also be of great value for improving the inherent qualities of natural forest stands by silvicultural methods. Criteria for the selection of good breeding stock, that is, for differentiating environmental and hereditary characteristics, are essential to good silvicultural practice in our natural stands. Improvement cuttings, thinnings, and especially selective logging, are probably the forester's best approach to mass selection, which will improve the inherent quality of our wild forests in direct proportion to the ability of the silviculturist to identify the select stock and leave it for seed purposes.

There is evidence that in our forest trees many valuable inherent characteristics are still to be discovered and isolated. A list of characters in which differences between individual trees of the same species have been reported as apparently hereditary is included at this point, because it indicates the range of hereditary variation and the possibilities in selection from our present wild stocks.

Rapidity of growth.
Growth habit.
Crown and stem form.
Leaf size, form, and color.
Growth periods.
Nut qualities and length of catkin.
Yield and composition of resin.
Proportion of resin adhering to faces as "scrape."
Color and correlated quality of wood.
Fiber length in wood.
Physical and chemical properties of wood.
Twisted grain in wood.
Resistance to frost, heat, light, and snow.
Resistance to disease and mistletoe.
Resistance to insects.

[5] This refers to the gum adhering to the wood exposed in turpentining, reducing the final yield appreciably.

These characters include not only those that are desirable from the standpoint of the forester (the producer), such as rapid growth and resistance to climatic conditions, disease, and insects, but also qualities important to the consumer, such as straightness of trunk and properties of the wood. Selection must be based on the requirements of the grower and the requirements of the user—so-called forest requirements and use requirements, respectively.

The silviculturist must look to the forest geneticist for possible correlations between readily recognized characteristics of the individual tree and its capacity for producing desirable progeny. Such correlations, even though they are only approximate, will be of great immediate value. This is especially true because the forester, managing a natural stand under a proper selection system, usually has an overabundance of seedlings, only a small percentage of which will be brought to maturity. If selection is for vigor of growth, the inherently vigorous individuals will normally take the lead and should make up a large proportion of the final crop. If other characteristics or qualities are desired, the forester using a selection system has opportunity to rogue his stand with each cutting or thinning, and undesirable individuals can be eliminated as their mature qualities become apparent.

Since the recognition of inherent quality is a key to the improvement of vast forest stands which for various reasons, such as inaccessibility or difficult environmental conditions, are not adapted to intensive forestry, well-planned investigations on this problem are justified. Much of the groundwork will not be strictly genetics. It will first be necessary to define clearly the desired characteristics or qualities. The relative desirability of particular qualities or characteristics will depend upon many things, including the species; the locality where it is to be grown; the purpose for which it is grown—watershed protection, soil-erosion control, tree crops or wood; and probable utilization—lumber, chemical wood, etc.

After the desired characteristics have been defined, methods for their accurate description or measurement must be devised. If measurement is not possible, then descriptions that will adequately bring out existing differences should be available. Rapidity of growth, usually a most important consideration in forestry, is easily measured. Measures for resistance to disease, insects, and climatic conditions will be fairly easy to develop. On the other hand, tree form or branching habit, very important from the standpoint of lumber quality, has been much debated but seldom adequately described or measured. Wood quality is even more elusive; "test-tube" methods for determining the physical and chemical qualities of wood are urgently needed. Tests that require cutting down the tree cannot be used to advantage by the forest geneticist, since a felled tree obviously cannot be used in breeding.

The progeny test is the generally accepted measure of inherent (breeding) quality. As applied to forest trees the method usually involves knowledge of the female parent only, since the seed is set by open pollination. Seed is collected from selected seed trees and the performance of the progenies of the individual seed trees is used as a criterion of breeding quality. This method eliminates the expense and

time involved in making controlled pollinations (fig. 9), but since the male parent is unknown the results must be interpreted with caution and can never provide exact genetical data on the mode of inheritance. This one-parent method may provide partially correct answers somewhat earlier than more exact methods, but a careful analysis of individual seed-tree progeny tests, which have been under way for a period of

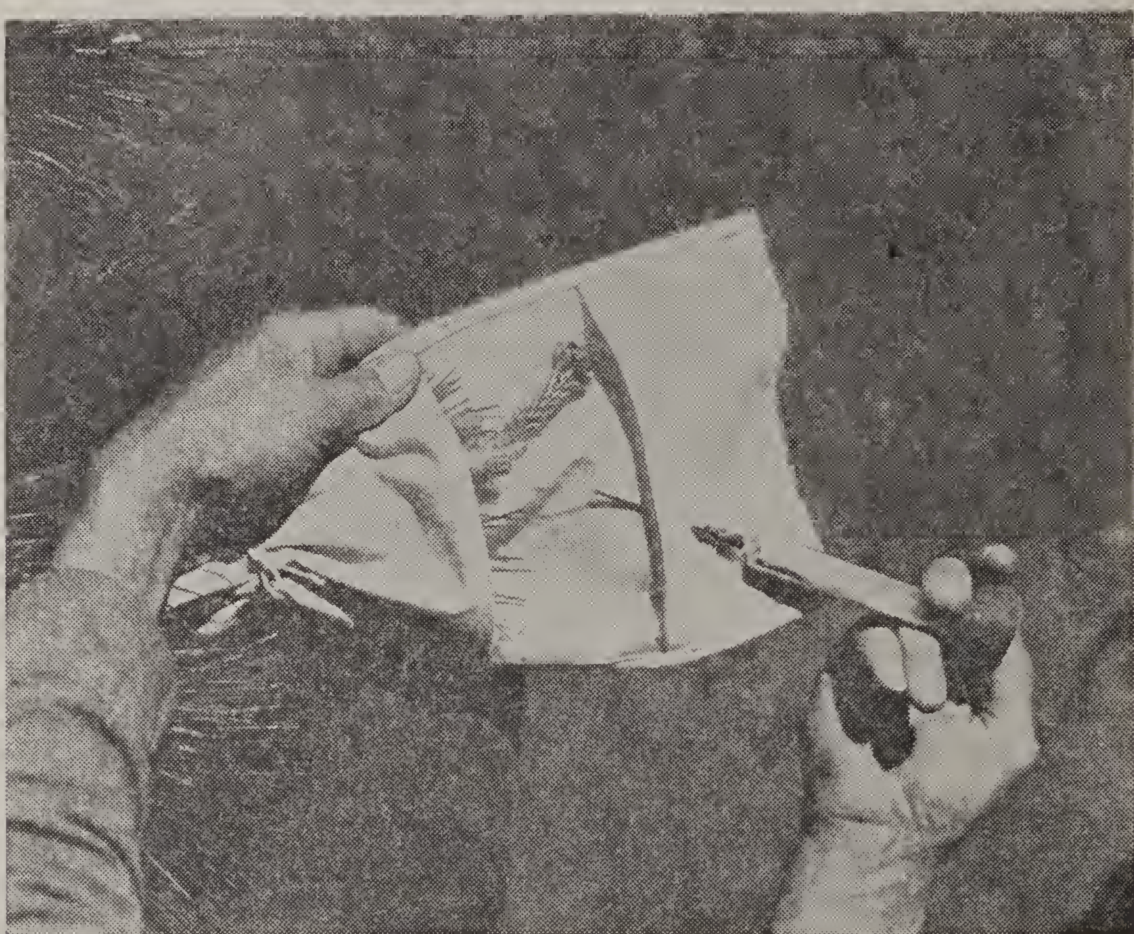

Figure 9.—Controlled pollination technique developed for work with pines at the Institute of Forest Genetics. A finely woven canvas bag with transparent window is placed over the flowering branches before the female flowers come into bloom. The sulphurlike pollen of the desired species of pine is placed in the barrel of a hypodermic needle and injected into the bag containing the ovulate flowers. The transparent window in the bag enables the operator to determine when the flowers are in the receptive stage and ready to receive the pollen.

years, will be highly desirable before further extensive trials of this kind are started.

Progeny tests involving full control of parentage are required to provide accurate data on heritability and mode of inheritance of particular characteristics. With this method both the male and the female parents are known. Self-fertilization, where possible, will be the quickest method of evaluation, but it is to be recognized that selfing in plants that naturally cross-breed often leads to degenerate lines, with loss of vigor. This must be considered in pure line breeding with forest trees which are apparently continually cross-pollinated.

Selective Breeding and Hybridization

Improvement by selection of the best individuals or strains from the wild stock is limited in scope. This procedure can hardly result in improvement of our best forest trees in the strict sense of the word, since the essence of the selection process is a sifting out of undesirable types and a segregation of the best strains already in existence.

Hybridization and selective breeding aim beyond this point and attempt to develop new types, which combine the desirable characteristics present in two or more individuals often widely separated geographically and sometimes racially. This possibility can be demonstrated in the hybrid progeny of a controlled cross-pollination, carried out at the Institute of Forest Genetics, between *Pinus attenuata* (knobcone pine) and *P. radiata* (Monterey pine), which combine the rapid growth of the pollen parent with the frost resistance of the seed parent (fig. 10); or in the Dunkeld larch, which is said to combine the excellent growth qualities of the European larch with the resistance to larch canker inherent in its Japanese parent. Cross-breeding may also result in the creation of entirely new characteristics, the expression of combinations of genes that would never occur under natural conditions. As has already been said, hybridization and breeding have infinite possibilities, but they are only at their beginning in forestry.

Figure 10.—Hybrids of knobcone and Monterey pines combine the frost resistance of one species and the vigor of the other. The short tree on the right represents the hardy but slow-growing knobcone pine. Beyond it are two trees of the badly frosted but rapid-growing Monterey pine. On the left are three hybrids of these two species. They have about the same vigor as their pollen parents, the Monterey pine, and are practically as hardy as their seed parent, the knobcone pine. All trees are 4 years old from seed.

A proper appreciation of breeding methods must be based upon the realization that the plant breeder is concerned with individual plants; that particular characteristics or qualities of the individual are of primary importance; and that the factors or combinations of factors in the germ plasm, which are responsible for the particular characteristics, are the raw materials that the breeder must shape into his ideal plant. With this in mind it is obvious that the most rapid progress in forest-tree improvement necessitates accurate information on the expression and behavior of the hereditary units in our various forest-tree species.

Mass Selection

In mass selection, groups of plants with more or less uniform characteristics are permitted to intercross. Close control of parentage is impossible, and gradual improvement results from continued selection of breeding stock on the basis of apparent quality. Improvement is

usually rather slow and the method does not provide accurate data that can be utilized for further breeding. The results attained depend to a considerable extent on the judgment of the breeder in selecting seed plants, and especially on his ability to distinguish between the effects of heredity and of environment. As noted previously, for the present this method seems best adapted to the improvement of natural stands that are to be handled under a selection system.

One-Parent Progeny Tests

The evaluation of the inherent quality of an individual tree on the basis of the progeny derived from uncontrolled pollination has already been discussed. The fact that only the female parent is known and that the unknown male parent has contributed half the germ plasm of the progeny considerably restricts any interpretation of the results. The method can probably be recommended only for preliminary survey purposes or where personnel is inadequate for the application of a more accurate procedure.

Pedigree Breeding Within and Between Varieties, Species, and Genera

Pedigree breeding with full control of parentage has been described in many of the articles in this and the 1936 Yearbook of Agriculture. Here both parents are known, and the progeny derived from selfing and from well-planned crosses provide an accurate measure of the respective parental germ plasm. Investigation by this method will not only determine which characteristics are inherent, but will also indicate the mode of inheritance—information that is indispensable for far-reaching improvement by intensive breeding and hybridization. The following discussion indicates pedigree methods applicable to forest trees.

Pure-line breeding, by selfing, is usually the most rapid method for the evaluation of hereditary characteristics. This will be possible only with trees that are hermaphrodite and self-fertile. In breeding trees that produce male and female flowers on separate individuals, or hermaphrodite trees that are self-sterile, crossing between selected individuals is necessary. With trees of this nature the nearest approach to pure-line breeding is to cross parents possessing the same characters, that is, breeding within a strain, variety, or species. Pure-line breeding and cross-breeding within a variety or strain will provide fundamental genetical data for the evaluation of inherent quality and the mode of inheritance, and may also provide superior races and strains for forestation. These superior types will be a source of superior germ plasm of known breeding value for further hybridization and breeding.

Combinations of desirable characteristics and modifications or new expressions of characters, due to new combinations or rearrangements of the determiners of heredity, are possible by cross-breeding between pure lines or varieties (intervarietal or intraspecific hybridization). Intervarietal crosses ordinarily represent the least difficult kind of hybridization. Varieties usually cross quite readily and produce fertile offspring. Valuable results may be apparent in the F_1 or first hybrid generation, and segregation in the F_2 or second generation (F_1 plants selfed or crossed) will produce new combinations from which the best individuals can be chosen for further selective breeding.

Crosses between different species of forest trees—a more remote relationship than between varieties—offer interesting possibilities. Such interspecific hybridization is often complicated by the fact that two species are difficult to cross, or by the partial or complete sterility of the resulting hybrids. If two species cannot be crossed directly it is at times possible to include them in the parentage of the final hybrid by breeding through a third species. In fact the utilization of three or more species in the breeding of daylilies has produced particularly valuable hybrids.

The first-generation hybrids of two forest-tree species are often quite uniform and more or less intermediate between the parent species. Segregation and recombination of characteristics occur in the second generation, and it is this generation that provides a very wide diversity of material for selective breeding. The procedure indicated is, therefore, (1) a small first-generation population, but (2) a large second-generation population, with (3) selective breeding continued with the most promising individuals of the second generation.

Interspecific hybridization of our forest trees is entirely justified, because it offers immediate improvement by combinations of desirable characters and the possibility of entirely new characteristics or qualities resulting from combinations of determiners that have never before been combined in any germ plasm. Many first-generation hybrids are more vigorous than either of their parents. This so-called hybrid vigor and any other valuable character can be maintained and utilized immediately if vegetative propagation is possible. Hybridization followed by polyploidy has also created individuals with unusual chromosome numbers that are superior to their parents and have their characteristics "fixed" so that they come true from seed.

Genera are, of course, even more distantly related than species. The comparatively few intergeneric plant hybrids that have been produced up to the present time have not been of practical value. Intergeneric hybridization is very greatly limited by specific differences in the requirements for fertilization inherent in distantly related plants. Furthermore, the progeny are seldom fertile. In spite of the difficulties involved, crosses between different genera may lead to valuable results, and excursions in this direction are warranted.

The Time Element in Tree Breeding

The improvement of forest trees by breeding and selection might appear, at first sight, to require centuries for completion. But although the work often requires a considerably longer time for the successful production of improved stocks than similar work with annual plants, various short cuts are possible.

The time element in breeding is dependent among other things on the relative age at which the individuals begin to bloom. Many trees produce flowers early in life—7-month-old chestnut seedlings occasionally bloom in nursery beds; fruit is often produced on chestnut trees before they are 5 years old; 4-year-old pines have been observed to mature cones; first-generation poplar hybrids 7 years old from seed have produced flowers and fruit. The blooming of more slowly maturing trees can usually be hastened by top-working or grafting on closely related mature individuals, and possibly in some species by

ringing, a light girdling of the trunk. Further work to determine the possibility of lowering the blooming age would be well worth while, since early blooming permits further cross-breeding or inbreeding and eventually speeds up the entire improvement program.

In order to take advantage of early blooming, correlations between juvenile and mature characteristics must be discovered. The fact that a tree blooms at an early age is of no value unless its characteristics at maturity can be predicted with fair accuracy. Such qualities as resistance to disease and winter hardiness can usually be determined with young trees, but in breeding for good forest form (habit of growth) it will be necessary to recognize and select for further breeding the young individuals that will develop good form at maturity.

The possibility for early results is indicated by the fact that selective breeding with daylilies, based on a knowledge of the mode of inheritance within the group, has fixed new combinations of germ plasm, derived from as many as four distinct species, into new types in five generations (Stout, 1936).[6]

Increased Chromosome Numbers, Polyploidy, Aneuploidy, and Mutations

Many valuable types of cultivated plants have arisen through an increase of chromosomes, originating in the somatic (body) cells, in the germ cells, or in the earliest divisions of the fertilized egg. The increase may consist in the duplication of a single chromosome, an unbalanced condition referred to as aneuploidy; or the chromosomes may be duplicated in multiples of the basic number (polyploidy). There may be multiplication of the chromosomes of a single individual (autopolyploidy), or a multiplication of both of the parental chromosome complements of a hybrid (allopolyploidy). Individuals with unbalanced chromosome complements may be maintained and multiplied as clones if vegetative propagation methods can be used.

There is evidence that merely a quantitative increase in chromatin material may be responsible for wide differences in characters that are of great practical value, and that polyploidy in hybrids, involving a quantitative increase in the chromatin material received from both parents, can produce new types as distinct as many of our present species. Polyploidy may result advantageously in (1) increased vigor; (2) increased variation; certain types of polyploidy may also give (3) increased fertility; (4) stability—that is, new types may breed true. On the other hand, polyploidy is sometimes directly responsible for increase in cell size, a contingency that is of particular significance since the chief product of forest trees is wood. An increase in the size of the wood fibers would be detrimental to the physical properties of some woods and would limit the use of others now used in the manufacture of particular grades of paper.

Of especial interest to forest-tree breeders are the facts that polyploidy has been induced by physical treatment of both somatic (body) and germinal tissue and by hybridization, and that balanced polyploids may breed true. If a superior self-fertile individual of this nature can be developed by physiological methods or by hybridization, it can immediately be propagated by seed. Such a strain

[6] See Bibliography, published in the Yearbook separate of this article.

would probably not cross readily with the native species and might thus maintain itself unmixed (homozygous) under natural conditions. The possibilities justify intensive effort directed toward the creation of polyploid strains.

New variations of the nature of mutations and bud sports, involving basic changes in the chromosome complement other than those due to duplication, occur occasionally in forest trees. The Lombardy poplar is said to be a mutant form of the European black poplar (*Populus nigra*) and the weeping beeches and birches are probably of similar origin. Although such variations have been primarily of value as ornamentals, it is possible that individuals of particular value for forestation purposes may be discovered.

Advantages in the Use of Vegetative Propagation

If vegetative propagation is feasible, any superior individual can be multiplied immediately and its characteristics perpetuated by the establishment of a clone. By vegetative propagation the breeder can

Figure 11.—One season's growth from roots of poplar hybrids cut back annually for the production of cuttings. The measuring rod is 9 feet high.

take advantage of the excellent individuals that may be produced at any stage of the breeding work, and since the components of the germ plasm are maintained in the somatic condition, the difficulties due to segregation of superior chromosome combinations are eliminated. Many so-called species are actually clones, and the uniformity among the individuals is due to the fact that the genetical complex is always passed on exactly as it was in the original plant.

Vegetative propagation does not lead to degeneration in clones. Investigations on cases of supposed senescence in clones have proved

that outside agencies such as environment or disease-producing organisms have been responsible.

The most promising hybrids produced in connection with the breeding project of the Oxford Paper Co. have been rapidly multiplied from cuttings at a unit cost lower than that of northern-grown nursery stock. Some idea of the rapidity of propagation by means of dormant cuttings may be gained from the fact that in Maine, with a comparatively short growing season, a 1-year-old poplar hybrid will produce 10 to 20 cuttings, at 2 years, 40 to 60 cuttings, and that after 3 years it will continue to produce 100 to 200 cuttings annually (fig. 11). If necessary, the rate of multiplication can be further increased by propagation from softwood cuttings. By this method small twigs 4 to 6 inches in length, cut from the mother plant throughout the growing season, are rooted in shaded, moist sand beds.

Figure 12.—Controlled hybridization in pines involves physical difficulties. This 77-foot ponderosa pine has 100 bags protecting the ovulate flowers from wind pollination.

Intensive investigation to develop a cheap method for the vegetative propagation of forest species that cannot now be economically reproduced in this way is fully justified; the best of our present wildlings and the elite individuals produced through breeding can then be utilized without further delay.

Need of Developing Technique

As in every new line of research, technical difficulties must be overcome before extensive breeding work can be undertaken. The breeder of forest trees is not only faced with the physical difficulties incident to the necessity of working with flowers at the tops of large trees (fig. 12), and often on the outside branches, but he is also handicapped at the present time by lack of accurate information essential to his work. Practically nothing is known of flower behavior, pollen-storage possibilities, artificial pollen-germination methods, sterilities, and incompatibilities in forest trees, and the affinities between species.

Accurate and detailed data on the flowering period of parent trees are essential for the successful planning of a breeding project. Information on blooming dates is not always sufficient; the receptive period of the female flowers is of vital importance in breeding. Where dichogamy, or the ripening of male and female organs at different times, occurs, it often necessitates storing pollen until it can be used, and since pollen viability in different species is known to vary from a few days to over a year, data on this point should be available. Assuming that the pollination has been made with viable pollen at the proper time and under favorable climatic conditions, incompatibilities or sterilities may still cause failure, and success can be attained only through a thorough understanding of such conditions.

The breeder of agricultural plants usually has more or less proven varieties and strains available that can be grown in adjacent plots in his experimental grounds. The breeder of forest trees must work with a wide diversity of species and varieties and often with widely scattered parent stocks—desirable parent types may be located hundreds of miles apart, and at best they are seldom within walking distance. Crossing such trees often requires the development of a new technique.

FUNDAMENTAL INVESTIGATIONS[7]

Fundamental genetical studies should certainly be started with forest trees. Chromosome studies and other cytological work necessary to a thorough understanding of the particular physical process involved in the transmission of hereditary characteristics in trees will be indispensable to the tree breeder. Cytological data will be an immediate necessity for effective work directed toward the compounding of polyploids. The solution of many problems will require the combined efforts of the geneticist, the cytologist, and the physiologist.

The forest geneticist should lay a broad foundation for such fundamental studies, but in doing so he should not overlook the fact that much of his early work must of necessity be more or less empirical in nature. It is generally recognized that the mode of inheritance of any particular character can seldom be predicted from a cytological study of the parents used; only actual crossing can supply the answer. It will be largely on the breeding work of the forest geneticist of today that the forest geneticist of tomorrow can safely continue his fundamental research, with the assurance that his line of attack is in the right direction.

A questionnaire on the subject of improvement in forest trees, which was submitted in connection with this Yearbook to various individuals and organizations both in the United States and abroad, asked for an opinion on the outstanding technical and practical problems that remain to be solved. In order to present the views of individual workers in various parts of the country with respect to their particular problems, it seems advisable to include their recommendations on genetical problems verbatim.

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[7] The following section is intended primarily for students and others professionally interested in breeding or genetics.

Lloyd Austin. California Forest and Range Experiment Station, Institute of Forest Genetics, Placerville, Calif.

Adaptability of selected strains and progenies.—While quite a little preliminary work has been done by the institute and other organizations in testing in a general way the adaptability of various forest species, only a bare beginning has been made in the formidable task of adequately testing and retesting the various selected strains and progenies of these species that are gradually being discovered. There can be no one best strain for all localities, and, as superior types are isolated by progeny tests and other methods, it will become imperative to try these out in a comprehensive way and under various climatic and soil conditions, so that eventually the best forms for each locality will be definitely known.

Hybridizing within species to combine vigor and cold-hardiness.—The institute's results seem to indicate that, at least in the case of *Pinus ponderosa*, most of the seed trees having the greatest inherent vigor will probably be found at relatively low elevations. Although proof is not yet available, it seems highly probable that these low-altitude forms will lack the degree of inherent cold-hardiness possessed by the forms from the higher elevations where much lower temperatures are encountered. This opens up a most promising line of genetical research in which artificial crosses would be made between low- and high-altitude strains, utilizing as parents in both cases the individual seed trees that the progeny tests show to be hereditarily superior. In this way it should prove possible to combine the rapid growth rate of one form with the desired cold-hardiness of the other, and thus greatly increase the adaptability and usefulness of the vigorous types. The institute has already accomplished practically this same combination of characters in the case of its cross of *P. attenuata* and *P. radiata*, and it should prove much easier to cross different altitudinal forms of *P. ponderosa* than to cross distinct species, which is nearly always difficult of accomplishment.

Improving the quality of seed from selected native seed trees.—Another promising line of genetical inquiry well worthy of investigation would consist in making tests in relatively isolated field plots to determine the practicability of using a carefully regulated thinning to improve the quality of the seed from the germinally superior individuals. The plan would be to cut out all those seed trees that the progeny tests show to be inferior. In this way subsequent natural cross-pollination would take place largely between the better types and seed with improved heredity should result. Such seed would be highly valuable for actual work in reforestation.

Roy L. Donahue. Mississippi State College, State College, Miss.

I would say that the needs for this region in particular with reference to forest genetics should include a testing of the various strains of black locust, especially different strains varying as to seed source.

Another type of research needed in Mississippi as well as throughout the entire South is in relation to the selection and breeding of a first-class Christmas tree. At the present time Christmas trees of excellent quality are imported from as far away as the West coast.

Duncan Dunning. California Forest and Range Experiment Station, Berkeley, Calif.

Studies should be made of the heritability of crookedness, excessive branching, spiral grain, and susceptibility to diseases.

Arthur H. Graves. Brooklyn Botanic Garden, Brooklyn, N. Y.

The most important of these requirements for rapid progress in forest tree improvement is reproduction by asexual methods—cutting, layering, budding, and grafting.

C. Heimburger. Petawawa Forest Experiment Station, Chalk River, Ontario, Canada. Urgent research problems:

The finding of a suitable strain of Norway spruce for pulpwood production, especially for the spruce regions in eastern Canada.

The finding of suitable strains of Scotch pine to replace jack pine, on sites not suitable for other more valuable native pines.

The production of a fully hardy rapidly growing aspen hybrid, combining the useful characters of the native aspens with added resistance to heart rot and better wood quality for the production of match stock and veneer.

A suitable propagation method for aspen poplars and their hybrids, better than the usual root-cutting methods.

Richard E. McArdle. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Other practical problems which demand solution involve the development or isolation of drought-resistant strains of native species (particularly ponderosa pine) for planting in the sand hills of the Plains States and in the high plains dry-land country immediately east of the mountains; determination of the best strains of Engelmann spruce and possibly other species for planting on denuded subalpine sites in the spruce type in Colorado, also in the bristlecone pine and limber pine types where administrative restrictions have been imposed upon the planting of native soft pines because of the blister-rust menace; improving lodgepole pine from a pathological standpoint to cut down losses in merchantable stands. While these problems are practical in their scope, their solution can follow only along highly technical lines of approach. This will require, therefore, the solution of technical problems either directly or under the supervision of qualified geneticists.

T. E. Maki. Intermountain Forest and Range Experiment Station, Ogden, Utah. Urgent research problems:

Determination of the inherentness of heavy or light seed producers.

Determination of vigor, natural pruning habit, etc., of progeny from different tree and age classes.

F. I. Righter. California Forest and Range Experiment Station, Institute of Forest Genetics, Placerville, Calif.

Breeding with polyploids.—In pine breeding projects the problem of inducing tetraploidy in hybrids may well be regarded as second to none in importance. The production of such forms, which, having their origin in hybridization, are yet something more than hybrids—namely, amphidiploid hybrids—will yield the following advantages: (1) Prolonged and costly selection tests of the F_2 and succeeding generations would be avoided; (2) such forms often are more vigorous than the parental species; (3) they are endowed with higher degree of fertility; (4) insofar as practical purposes are concerned, they breed true; and (5) when they, in turn, are hybridized the F_2 generation will consist of greater varieties of new forms for investigation than does the F_2 of the ordinary species or varietal cross.

Polyploidy has not been reported for the pines, and it probably will be necessary to induce tetraploidy before any further breeding with polyploids will be possible; however, the tetraploids should constitute sufficient justification in themselves for work in this field. The possibility of realizing the benefits which may be expected from the production of amphidiploid hybrids is not more remote than is that of achieving comparable results through selection tests subsequent to hybridization. In fact, the latter method of proceeding may well be regarded as the last desperate resource in the field of hybridization with pines, whereas the former offers such valuable results that its immediate adoption is fully justified.

Tetraploidy has developed in sterile species hybrids spontaneously but such appearances have been so rare that it will not be practicable for the pine breeder to rely on the production of such forms through the operation of Nature alone. Artificial means are practically a requisite for such work. Fortunately, means of inducing tetraploids have been developed. The chief method developed thus far consists of subjecting the zygote to heat treatments during the first few cell divisions following fertilization. Under the influence of such treatments a newly formed embryo may undergo nuclear division without the laying down of a dividing wall. This process results in the formation of a cell having the double number of chromosomes. The further growth of the embryo results in an individual that is entirely tetraploid. Attempts to induce tetraploids in hybrids may prove difficult at first, because of the difficulty of ascertaining when fertilization occurs,

for in most of the pines fertilization occurs about a year after pollination; however, the problem should yield to the combined attacks of the geneticists, the cytologist, and the physiologist.

Cytological, taxonomical, and physiological studies.—Cytological, taxonomical, and physiological studies of the genus *Pinus* will contribute immeasurably to the progress of the work of breeding superior timber trees, because they ramify into all phases of the work. Such studies will be started in the near future.

Paul O. Rudolf. Lake States Forest Experiment Station, St. Paul, Minn.

As far as forest genetics goes, the field has barely been scratched. So many problems remain to be solved that it is difficult to know where to begin in listing what remains to be done.

From the practical standpoint it seems desirable to extend source-of-seed tests to include all species used in forestation work to indicate within what limits seed can safely be used in other than native localities for various species. The selection of individual trees and stands of particularly desirable characteristics, followed by the determination of the extent to which these characteristics are heritable by their progeny, is another useful field of investigation. Cross-breeding and hybridizations which have been begun with certain early-maturing species of *Populus*, *Salix*, and *Larix* here and abroad might well be extended to other species in general although the immediate practical value may not be as great as for other studies.

In the field of pure genetics much of value might be accomplished by a study of the mechanics of inheritance for important tree species particularly with a view to determining how certain desired characteristics are transmitted and to what extent such functions may be modified or controlled.

Philip C. Wakeley. Southern Forest Experiment Station, New Orleans, La.

Further work upon the pines (to say nothing of the hardwoods) is urgently needed in:

a. Effect of climatic-zone source of seed.
b. Effect of major soil type source; e. g., deep sands.
c. Effect of female parent source alone on progeny (of direct application in seed collection).
d. Effect of both parents upon progeny (of direct application in marking for natural reproduction cuttings).
e. Development of very tall strains for high yields, structural timber, and piling.
f. Development of strains high in naval stores yield.
g. Development of brown spot-resistant *P. palustris*, windfirm *P. caribaea*, and tip moth-resistant *P. taeda* and *P. echinata*, for artificial reforestation.

APPENDIX

As a part of the cooperative survey of plant and animal improvement, a comprehensive questionnaire requesting information on investigations pertaining to improvement in forest trees was sent to approximately 150 institutions and private agencies in various parts of the world. Summaries of the reports received from those organizations or individuals engaged in work of this nature are included here. The replies received present a rather complete account of forest-tree improvement work in progress throughout the United States, but the replies from foreign sources are rather limited.

United States—Federal Agencies

Bureau of Plant Industry, Division of Forest Pathology

3. Hybridization

Progeny of the following crosses, being grown for forest-tree improvement, are under observation:

Castanea mollissima × *C. dentata*, 272 seedlings 1 to 8 years old.
C. crenata (forest types) × *C. dentata*, 33 seedlings 1 to 4 years old.

C. crenata (forest types) × *C. mollissima*, 44 seedlings 1 to 5 years old.
C. mollissima × *C. henryi*, 16 seedlings 1 to 9 years old.
C. crenata (forest types) × *C. henryi*, 3 seedlings 1 to 2 years old.

In general, hybrid vigor is present in these first-generation trees in the order as listed.

Progeny of the following crosses apparently should be valuable in the production of mast crops and for soil conservation planting:

C. pumila × *C. seguinii*, 21 seedlings 1 to 5 years old.
C. mollissima × *C. seguinii*, 19 seedlings 3 to 6 years old.
C. crenata × *seguinii*, 24 seedlings 1 to 6 years old.

Reciprocal crosses are usually made as a matter of routine. From the genetic viewpoint no significant differences have been found in their progeny. Seedlings of crosses with a dwarf Chinese chestnut, *C. seguinii*, tend to be everblooming in habit, a dominant character inherited from that species. Additional crosses are being made between the several American chinquapins and the various true chestnuts from Asia. Here again selections will be made of individuals suitable for mast-crop production and soil-conservation planting, but such selections are not expected to carry the everblooming habit.

Present work is now largely confined to the production of second-generation stock and incidentally to the study of genetic phases of the problem with special regard to the inheritance of resistance to the chestnut blight.

Forest Service, Appalachian Forest Experiment Station [8]

1. Seed Origin

Robinia pseudoacacia (black locust)

One-year-old seedlings from seed collected from seven Appalachian sources (West Virginia, Virginia, North Carolina, 1,800 to 3,000 feet elevation) were set out in test plantations at Bent Creek in 1935. Seed from an additional five sources (three foreign, two American) was used to establish test plots in South Carolina, West Virginia, North Carolina, and north Georgia in 1936. In both experiments significant differences between the average height of seedlings from different sources were observed at the end of the first season's growth. Some difference was also indicated in form of bole.

In the fall of 1935, 20 superior and 20 average seedlings were selected in each of 10 nurseries (in North Carolina, South Carolina, Tennessee, Mississippi, Virginia, and West Virginia). These were planted in test plots in the Bent Creek Experimental Forest in 1936 to determine the possibility of selecting superior strains from 1-year-old seedlings.

2. Individual Seed-Tree Progeny Tests

Pinus taeda (Loblolly Pine)

Seedlings from 122 individual seed trees were out-planted in 1936 for progeny study. The purpose of this experiment is to determine the effect of the female parent on the germination and growth of seedlings, with the ultimate aim of determining the desirable characteristics of loblolly pine seed trees.

California Forest and Range Experiment Station, Institute of Forest Genetics

1. Seed Origin

Extensive tests of species and geographical races are well under way. The arboretum contains approximately 100 species and named varieties of the genus *Pinus* and inumerable climatic forms of many of these species; seed has been obtained from 40 countries. Growth records, taxonomic records, phenological records, injury records, and seed, sowing, and germination records are taken on all of these test trees, which range in age from 4 to 15 years. Among the fastest growing species so far tested are *P. radiata* (Monterey pine), *P. pinaster* (cluster pine), *P. taeda* (loblolly pine), *P. coulteri* (Coulter pine), *P. patula* (Toluca pine). In most tests *P. radiata* has surpassed all other species in rate of growth, particularly in height growth.

The great majority of all the pine species tested have possessed sufficient cold-hardiness to enable them to survive at the institute at Placerville, Calif., where

[8] At Asheville, N. C.

the lowest temperature on record is 16° F. Exceptions have occurred in the case of certain tropical species, such as *Pinus tropicalis*, *P. insularis*, *P. canariensis*, and *P. merkusii*. These species do not seem to possess enough inherent resistance to cold to be of practical value in any of the important forest regions of the United States, but they are of interest to tree breeders who may wish to hybridize them with hardier species.

Tests with approximately 30 species of pine are under way in cooperation with numerous organizations (31 in the United States and 1 each in England, Scotland, and Denmark) to determine the adaptability of the various native and foreign species.

In addition to the work with pines, 35 species of conifers, representing 17 genera, and 20 species of hardwood trees, 13 genera, are included in the arboretum.

These investigations will eventually indicate the value and adaptability of geographic races and strains of many important timber trees, and the arboretum will be a source of superior germ plasm for future selection and breeding work.

2. Individual Seed-Tree Progeny Tests

Progeny tests have been undertaken with 10 species and varieties of pines. All seed is collected from tagged seed trees, which are fully described and have their location recorded in map form. Seed has been gathered from a total of 2,609 separate trees located in 289 field plots. Many thousands of seedlings have been grown in the nursery and of these 1,843 progeny trees have appeared worthy of further trial in forest plantations to test the permanence of the early differences apparent in the nursery.

As rapidly as the desirable seed trees are discovered, they become for many years potential sources of relatively large quantities of superior seed for practical reforestation. Trees selected in this way are also valuable for use in breeding experiments designed to develop still better types.

P. ponderosa (ponderosa pine)

The largest single progeny test was started in 1929 with seed from 742 individual trees of this species and its varieties *scopulorum* and *jeffreyi*. (*Pinus jeffreyi* is considered a separate species by Sudworth in his Check List of the Forest Trees of the United States.) The seed trees represented in this test are scattered over 60 counties in 12 Western States and British Columbia.

Results already indicate that within this species and its varieties there are innumerable local strains, each with distinct morphological and physiological characteristics. Even within a local geographical strain, individual seed trees vary strikingly in their ability to produce seedlings that are superior in vigor and in habit of growth.

Although the hereditary vigor of ponderosa pine in the central Sierras of California tends to decrease markedly with an increase in the elevation of the seed source, certain individual seed trees have been found at relatively high elevations which, contrary to the general tendency, have high inherent vigor. These are of outstanding value since they probably have the ability to produce offspring that will be both fast-growing and cold-hardy.

Eldorado County, Calif., seems to be about the center of the optimum belt for ponderosa pine, and an intensive progeny test is to be started in the spring of 1937 using seed already collected from about 1,000 trees growing in this county and closely adjoining areas. Seed-collection activities have been so directed that there has resulted a relatively complete sampling of the local strains within this limited area. The field plots are distributed over an altitudinal range of more than 8,000 feet, extending from an elevation of 150 feet up to 8,400 feet.

It is hoped from these various progeny tests to determine whether or not there are any correlations between the visible characters of the seed trees and the nature of their progenies, and to ascertain any relationships that may exist between the environment of a seed tree and the growth, hardiness, etc., of its progeny.

Juglans (walnuts)

Walnuts are being studied primarily from the point of view of developing superior timber trees, and their nut-producing characteristics are a secondary consideration in these experiments. Tests have been undertaken with the progenies of 272 individual trees of 16 species and hybrids of walnuts. After growing the progenies for 2 years in the nursery, 421 seedlings were selected and

set out in permanent plantations. There have been marked differences in the growth of the different progenies.

In some cases natural cross-pollination between species apparently took place during the spring prior to the collection of the nuts, for certain nonhybrid seed trees yielded progenies that were partly hybrid in nature. The nuts were graded into three sizes before sowing, and it was later discovered that most of the hybrids, some of which were very vigorous, came from the large nuts. Hybridization apparently stimulated the development of the nuts, and this may provide a simple method for selecting a high proportion of naturally hybridized nuts from walnut trees exposed to pollen of other walnut species.

3. HYBRIDIZATION

Controlled hybridization has been a very important part of the work carried on at this station.

Progeny of the following artificial crosses (made at the institute) are under observation:

P. attenuata (knobcone pine) × *P. radiata* (Monterey pine). Hybridity certain. Progeny, 8 years old, shows rapid growth of pollen parent combined with frost resistance of seed parent. Appears to be weakly fertile. Twenty-eight trees.

(*P. attenuata* × *P. radiata*) × self. (F_2) hybridity certain. Progeny 3 years old. Five trees.

P. caribaea (slash pine × *P. taeda* (loblolly pine). Hybridity probable. Progeny 3 years old. Ten trees.

P. echinata (shortleaf pine) × *P. taeda*. Hybridity probable. Vigor of 2-year-old progeny exceeds that of seed parent. Fourteen trees. Seedlings now 3 years old.

P. ponderosa var. *jeffreyi* × *P. ponderosa*. Hybridity certain. Vigor of 3-year-old progeny greatly exceeds that of seed parent. A potentially valuable cross.

P. rigida (pitch pine) × *P. taeda*. Hybridity probable. Four trees. Age 3 years.

The following artificial crosses were made with various species and varieties of *Juglans* in 1927:

J. hindsii × Royal hybrid; 12 hybrid seedlings obtained.
Royal hybrid × Royal hybrid; 7 hybrid seedlings obtained.
Royal hybrid × *J. mandshurica;* 1 hybrid seedling obtained.
Royal hybrid × *J. regia;* 3 hybrid seedlings obtained.
J. hindsii × *J. hindsii;* 3 seedlings obtained.
Royal hybrid × *J. hindsii;* 1 hybrid seedling obtained.

Central States Forest Experiment Station [9]

1. SEED ORIGIN

Robinia pseudoacacia (black locust)

Experimental work was started in 1935 with approximately 22 strains of black locust, including the shipmast locust (var. *rectissima*), in a search for strains resistant to locust borer.

Yellow pines

Work of a minor nature is in progress with local strains of shortleaf, pitch, and Virginia pines.

Intermountain Forest and Range Experiment Station [10]

1. SEED ORIGIN

Pinus ponderosa (ponderosa pine)

Some experimental work on importance of seed origin is being carried on but work is too recent for definite observations.

Future plans call for investigations on regional and altitudinal strains of this species.

[9] At Columbus, Ohio.
[10] At Ogden, Utah.

Lake States Forest Experiment Station [11]

1. Seed Origin

Pinus resinosa (Norway pine)

Three plantations each containing progeny from 154 seed sources (Lake States, Pennsylvania, New York, New England, Quebec, Ontario) were established in 1931 and 1933. Seed collection was mostly from "individual tree" or "small group" but some "limited locality" and general collections are also represented. Differences are already apparent in vigor, winter hardiness, and drought resistance.

Pinus sylvestris (Scotch pine)

Progeny from 27 seed sources (United States and foreign) were included in the plantations of Norway pine (1931 and 1933). Differences have been observed in the nursery and in the field between northern and southern stocks in size of seedlings and color of foliage—stock from southern sources is larger and tends to have darker green foliage. Northern stocks showed markedly superior winter resistance, 1935–36.

Picea (spruce)

In a search for fast-growing spruce for pulpwood, plantations of nine different spruces were established in 1936. The following species were used: *P. glauca* (white spruce) six seed sources; *P. excelsa* (Norway spruce) six sources, mostly from the Union of Soviet Socialist Republics; *P. rubra* (red spruce) two sources; *P. glauca albertiana* (Alberta spruce); *P. mariana* (black spruce); *P. glehnii* (Sakhalin spruce); *P. orientalis* (Oriental spruce); and *P. omorika* (Serbian spruce) Seed of the last five each from one source.

2. Individual Seed-Tree Progeny Tests

Fraxinus pennsylvanica lanceolata (green ash)

Progenies of 83 individual trees (from North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Oklahoma) were grown in two nurseries (York, Nebr., and Denbigh, N. Dak.). Variations between individual progenies were apparent in the nursery; seed from the northern area exhibited slow germination and growth. Seedlings from northern stock were much smaller, with smaller, darker green leaves, and shorter growing periods than southern stock. Transplants of the York stock were field-planted in Nebraska in the fall of 1936, but are insufficient in number to give conclusive results.

Artificial drought tests indicated a definite decrease in drought resistance from north to south and from west to east (definitely correlated with climate). The greatest difference was observed between plants from the northwest portion of North Dakota and the eastern portion of Nebraska, Kansas, and Oklahoma. The evidence indicates that there are inherently different climatic races. Local variations within a single subdivision of the plains region were also observed.

Pinus resinosa (Norway pine)

Approximately 100 of the 150 seed lots mentioned under Seed origin were from individual seed trees. A few of the individual progenies are sufficiently outstanding to indicate that selection and breeding might produce a superrace of Norway pine.

Pinus sylvestris (Scotch pine)

Some 20 of the 27 seed lots obtained for provenience study were from individual seed trees growing in the Lake States. No significant differences have been observed to date.

Northeastern Forest Experiment Station [12]

1. Seed Origin

Pinus sylvestris (Scotch pine)

Two-year-old seedlings of two strains of Scotch pine, Riga and Austrian, were outplanted in 1925 on the Mount Toby Demonstration Forest in Massachusetts. After 11 years the Austrian Scotch pine has made 2 to 3 feet better height growth

[11] At St. Paul, Minn.
[12] At New Haven, Conn.

and greater diameter growth than the Riga strain, and it appears to have a superior stem form.

Studies are under way to determine whether a single vigorous stock of Scotch pine is suitable for planting in all parts of the Northeastern region. In 1932, 2–2 planting stock from a single seed source (Booneville, N. Y.) was planted in 10 test plots of 1,200 trees each throughout the Northeastern States. Additional plantings were made in 1934 using 1–2 and 2–0 stock from the same source. No significant results have been noted up to the present time.

A rather comprehensive forest-genetics project is now being started. It is anticipated that this project will include practical and fundamental research on seed origin, adequate progeny tests, selective breeding and hybridization. Although the primary emphasis will probably be placed on deciduous forest trees, some work with conifers, particularly with reference to disease and insect resistance of native species, will undoubtedly be advisable. The station also expects to cooperate with the Oxford Paper Co. in continuing the valuable hybridization work with poplars started by that organization in 1924.

Northern Rocky Mountain Forest and Range Experiment Station [13]

1. Seed Origin

Pinus ponderosa (ponderosa pine)

Twenty-two experimental plots in northern Idaho contain progenies from seed collected in 22 geographic localities in Oregon, California, Idaho, Washington, Montana, South Dakota, Colorado, Arizona, New Mexico, and Utah. The trees are now 23 to 27 years old from seed.

Figure 13.—Racial differences in ponderosa pine: *A*, The open, plumelike arrangement of long, slender needles of the North Pacific and Northern Rocky Mountain races is easily distinguished from *B*, the compact and bushlike growth of short, stout needles of races from the east slope of the Rocky Mountains.

[13] At Missoula, Mont.

A number of distinct races have developed under natural conditions in ponderosa pine, which is widely distributed throughout the Western States and is subject to a great diversity of environmental conditions (fig. 13). Progenies from sources west of the Continental Divide in the North-Pacific and Northern Rocky Mountain regions have long, slender, flexible needles with slight to moderate thickening of the hypoderm cell walls, prevailingly in three-needle fascicles (fig. 14, *A*). Trees from east of the Continental Divide and in Colorado and Utah have foliage prevailingly in two-needle fascicles with short, thick, stiff needles with extremely thick hypoderm tissues (fig. 14, *B*). Trees from the Arizona-New

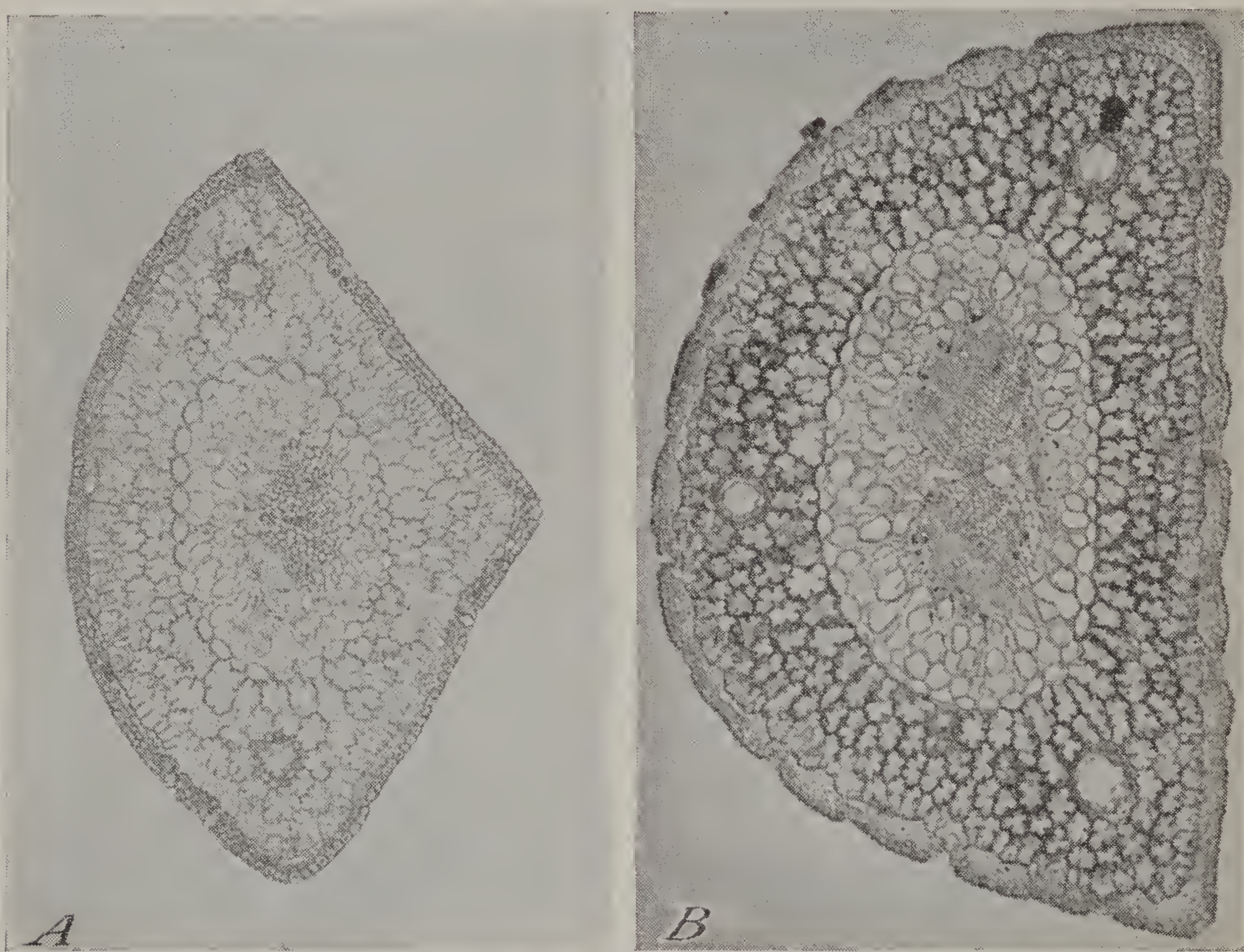

Figure 14.—Races of ponderosa pine show inherent differences in needle structure: *A*, An example of the thin hypoderm layer and lack of stomatal depressions of the long-needle type shown in figure 13, *A*; *B*, thicker hypoderm layer without stomatal depressions, characteristic of the short-needle type illustrated in figure 13, *B*.

Mexico Plateau have preponderantly three-needle fascicles, with moderate length and slenderness of needles, but with thick hypoderm structure. As these pronounced differences in foliage were found to be the same in trees of the parent localities, the conclusion is that these characteristics are strongly heritable.

Progenies that originated in localities within the northern Rocky Mountains, where the climate was similar to that of the experimental site, have made the greatest growth in height and diameter. Those from regions of more severe climates in Colorado, Utah, Arizona, and New Mexico have made the least. The slowest growing progenies in the experiment have reached an average height and diameter only half that of the fastest growing offspring. Comparison of progenies with trees growing in parent localities shows strong inheritance of growth rate in the new environment, except that the tendency is less marked where the progeny came from a region of more favorable climate.

Relative degree of hardiness was revealed by a sudden steep drop in temperature of 57° F. on December 15, 1924. Two progenies from the mild Pacific coast region were practically eliminated. The progenies from regions of the most rigorous winter climates suffered little or no loss by this freeze.

The results to date indicate that the most suitable seed source for planting in northern Idaho is from Republic, Wash., to the Continental Divide and from the Salmon River to the Canadian boundary. Introductions from the mild climate of the Pacific coast are subject to loss from sudden and severe temperature changes, which may occur periodically in Idaho. Although an introduced tree may be perfectly adaptable to the climate, it may, because of slow growth, be decidedly unsuitable for timber growing in northern Idaho. On this basis seed from Black Hills and southeastern Montana sources would be unsatisfactory, and Colorado seed would prove decidedly so.

Pacific Northwest Forest Experiment Station [14]

1. SEED ORIGIN

Pseudotsuga taxifolia (Douglas fir)

Five replicative plantations were established in 1915 with seed from 13 localities (northwestern Washington to central-western Oregon, 100- to 3,850-foot elevations) to study climatic and geographic races within the Pacific coast form. Progenies from individual trees representing variations in age, form, infection by wood-rot fungi, and site conditions were planted under separate pedigree numbers. No gross differences have been observed in morphological characteristics (leaves, crown, stem, flowers) between progenies from different seed sources. A significant and constant difference was observed in the relative time at which the various progenies burst their buds in the spring. Different progenies also varied in their susceptibility to late-spring frost injury. The progenies of certain individual parents were significantly taller than those from other parents growing in the same locality. The progeny from two of the seed-source localities made outstandingly good height growth on every plantation.

Pinus ponderosa (ponderosa pine)

Plantations were established in 1926 for a study of geographical races of this species. Results indicate that local stock is doing best in growth and survival. Progenies from different seed sources are already beginning to show rather distinct variations in the appearance of the foliage.

Rocky Mountain Forest and Range Experiment Station [15]

1. SEED ORIGIN

Pinus ponderosa (ponderosa pine)

Test plantations were established at Fremont in 1915 and 1916 with seed from seven sources (five Colorado, one Wyoming, and one South Dakota). Altitude range of seed sources was from 5,200 to 9,000 feet. A second test plantation was established in 1920 with seed from eight sources (one each from Montana, Arizona, California, Oregon, South Dakota, and three from Colorado). Data are available on survival, height, and form. The results from the standpoint of survival, rate of growth, and winter-hardiness point conclusively to the futility of using any but Colorado (not including southwestern pine type) and possibly Black Hills seed.

Test plantations were established in the Nebraska National Forest (1926) with seed from eight sources (Nebraska, South Dakota, Colorado, Arizona, New Mexico). The results indicate the superiority of local Nebraska seed. Southwestern and central Rocky Mountain stocks have been extremely susceptible to tip-moth attack. A segregated seed area has been established.

Pinus contorta (lodgepole pine)

A plantation at Fremont now 21 years old includes trees from seed collected from nine localities in Wyoming and Colorado. There is also a 17-year-old plantation, established with stock from 14 sources from approximately the same general region. In general the nearest seed sources have given the best results, but the extent of variation within a seed progeny largely eliminates the significance of the group performance.

A test planting in the Medicine Bow Forest, Wyo., is now 17 years old; seed from three sources (local, southern Wyoming, western Colorado). The relative survival and performance have been in inverse ratio to proximity of the seed source to the experimental area.

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[14] At Portland, Oreg.
[15] At Fort Collins, Colo.

Pseudotsuga taxifolia (Douglas fir)

A 20-year-old plantation at Fremont includes stock from 11 national forests (6 in Colorado, 5 in Wyoming) and 15 climatic sources. Last observations (1923) indicate that local stock is decidedly superior in survival and height growth. Wyoming stock failed completely.

Picea engelmanni (Engelmann spruce)

A plantation on the east slope of Pike's Peak (elevation 10,500 feet), 24 years old, contains 10 climatic strains from 6 Colorado National Forest seed sources. Results are not conclusive.

2. Individual Seed-Tree Progeny Tests.

Pinus ponderosa (ponderosa pine)

Test plots were established in 1932 at elevations of 7,200 feet and 9,100 feet in the Pike's Peak locality with progeny from eight individual parent trees representing a 2,000-foot altitudinal range within the same locality. The lower plantation was eliminated by drought. In the upper plantation survival shows a fairly regular increase from low to high elevation sources.

Progeny from individual mistletoe-susceptible and presumably mistletoe-resistant trees are being tested in two 4-year-old plantations at Fremont station.

Three plantations (3, 4, and 6 years old) in the Nebraska sand hills include progeny of individual trees selected because of superior development and freedom from Peridermium.

Pseudotsuga taxifolia (Douglas fir)

Progeny of individual parent trees possessing peculiar branching habits are under observation in two plantations at Freemont (6 and 8 years old).

3. Tree Breeding

Artificial crosses between individuals of an apparently mistletoe-immune strain of *Pinus ponderosa* (ponderosa pine) have been successful. Seedlings are now 4 years old.

Southern Forest Experiment Station [16]

1. Seed Origin

Pinus taeda (loblolly pine)

Test plots were established in 1927 at Bogalusa, La., with trees from seed collected in Louisiana, Texas, Arkansas, and Georgia. Observation in the spring of 1936 (trees 9 years in field) showed local Louisiana seed definitely superior in growth rate. Other significant differences may exist.

Pinus palustris (longleaf pine), *P. caribaea* (slash pine), *P. taeda* (loblolly pine), *P. echinata* (shortleaf pine)

Test plantations were started on the Palustris Experimental Forest (1935–36) with stock from seed of various geographic sources. The following species were used: *P. palustris* (eight sources), *P. caribaea* (nine sources), *P. taeda* (two sources), *P. echinata* (two sources).

Seed of the following four species was obtained from 40 different sources in 1935: *P. palustris* (11 sources), *P. caribaea* (7 sources), *P. taeda* (12 sources). *P. echinata* (10 sources). Seedlings from seed of practically all sources for each species were grown at or near each point of origin, for planting during the 1936–37 planting season. The purpose of this is to test every geographic strain both in its own locality and in every other locality included in the study of that species. In at least one nursery distinct differences in size and in rate of maturing were apparent in the fall of 1936, the most conspicuous being between shortleaf pine seedlings from Pennsylvania and from Texas seed.

2. Individual Seed-Tree Progeny Tests

Pinus palustris (longleaf pine)

A test plantation was started in 1936 with 300 seedlings from parents high in naval stores yield and from parents low in yield.

[16] At New Orleans, La.

3. Tree Breeding

Pinus palustris x *P. caribaea*, hybridized in 1929, produced approximately 24 hybrid seedlings intermediate between the parents in stem, foliage, and bud characteristics, growth habit, and rate of growth. X *P. sondereggeri* (F_1) was crossed with *P. palustris*, *P. taeda*, and X *P. sondereggeri*. A few seedlings were obtained from each of these crosses and were planted out in 1933.

Southwestern Forest and Range Experiment Station [17]

1. Seed Origin

Pinus ponderosa (ponderosa pine)

Tests of climatic races are under way at the Fort Valley station. Results indicate that seed from California and the northwest portions of the United States invariably germinate less rapidly and produce larger, more succulent, but noticeably less hardy seedlings than local seed. Seed from Colorado, Utah, and Black Hills produce plants much like those from local seed, but Black Hills seedlings always show characteristic differences in color and form, and 20 years after planting are beginning to show signs of decline.

Tennessee Valley Authority, Forestry Division [18]

2. Individual Tree Selection

The tree crop unit of the Forestry Division has been interested in the selection of individual forest trees that combine desirable timber quality with production of high quality and quantity of fruit (nuts, acorns, berries). This work has been carried on through prize contests and through direct scouting. Up to the present time, one black walnut, two black locusts, two honey locusts, one ash, one hickory, and two oaks have been discovered which appear to merit special study. These individuals are being multiplied vegetatively by grafting and budding.

3. Tree Breeding

The tree crop unit initiated a project in hybridization and breeding in the spring of 1936. During this first year, a total of approximately 5,000 artificial pollinations were made with 72 species, varieties, and clones of the following 10 genera: *Juglans* (walnut), *Hicoria*, syn. *Carya* (hickory), *Corylus* (hazel), *Castanea* (chestnut), *Quercus* (oak), *Asimina* (pawpaw), *Amelanchier* (serviceberry), *Gleditsia* (honeylocust), *Robinia* (black locust), and *Diospyros* (persimmon).

The purpose of this breeding work was to produce trees combining high productivity and high quality of fruit (nuts, berries, acorns, pods) with desirable timber qualities. Such superior trees are needed for tree-crop planting and will, before maturity of the timber crop, pay their way by the annual production of food for man, stock, or game.

The severe spring drought in eastern Tennessee resulted in the loss of a considerable portion of seed that had originally set to cross-pollination.

United States—State, Private, and Endowed Agencies

Brooklyn Botanic Garden [19]

3. Tree Breeding

Controlled breeding experiments were undertaken in 1930, to produce a chestnut with inherently good timber form and high resistance to or immunity from the chestnut blight disease. The work was started with Japanese and American chestnuts, but in recent years additional species, varieties, and hybrids have been used as parent stocks. Some of these hybrids are now 5 years old. Up to the present time, the following *Castanea* hybrids have been produced ((R) indicates reciprocal crosses between the parents):

C. crenata (Japanese c.) × *C. dentata* (American c.)
C. mollissima (Chinese c.) × *C. dentata* (R)
C. S8 × *C. dentata* (R)
C. S8 × *C. crenata* (R)
C. crenata × (*C. crenata* × *C. dentata*) (R)

[17] At Tucson, Ariz.
[18] At Norris, Tenn.
[19] At Brooklyn, N. Y.

(*C. crenata* × *C. dentata*) × *C. mollissima* (R)
(*C. mollissima* × *C. pumila* (chinquapin) × *C. dentata*
C. crenata × *C. seguinii* (Chinese chinquapin)
C. mollissima × *C. seguinii*
(*C. crenata* × *C. dentata*) × *C. dentata*
(*C. crenata* × *C. dentata*) × (*C. crenata* × *C. dentata*)

(NOTE.—S8 is apparently a combination of *C. crenata* and *C. pumila;* made by Walter Van Fleet, U. S. Department of Agriculture.)

Many of the *C. crenata* × *C. dentata* hybrids give promise of timber types and appear to be resistant to chestnut blight. So far, they have been subjected only to natural infection, but in 1936 all hybrids were artificially inoculated. It is too early to determine the results of these inoculation tests. Some of the hybrids bloomed at 3 years of age; these were immediately used for further hybridization.

Fox Research Forest [20]

1. SEED ORIGIN

Investigations originally started by the Brown Co. are being conducted with Scotch pine, Norway spruce, and European larch. The purpose of these experimental plantations is to determine the most desirable proveniences for reforestation in New Hampshire. Most of the plantations are too young to provide pertinent information.

New York State Conservation Department, Bureau of Investigation [21]

1. SEED ORIGIN

Pinus sylvestris (Scotch pine)

Four generations, ranging in age up to 30 years, are now available for study. Observations to date indicate the possibility of rust-resistant strains and two apparently inherent growth forms; a straight-boiled, small-limbed type with small pointed crown, and a fairly straight-boled, large-limbed type with large bushy crown.

New York State College of Forestry [22]

2. SEED ORIGIN

Investigations with climatic varieties of two species of *Picea*, five species of *Pinus*, and two species of *Larix* have been started on the Pack Demonstration Forest, Warrensburg, N. Y.

Oxford Paper Co. in Cooperation with the New York Botanical Garden [23]

3. TREE BREEDING

A breeding project was initiated in the spring of 1924 to develop new hybrid poplars of particular value for pulpwood reforestation in Maine (Stout and Schreiner, 1933).[24] A total of approximately 13,000 hybrid seedlings was obtained from 99 different cross combinations between 34 different types of *Populus*, as follows:

The parents are arranged in alphabetical order within the main groups of poplars, and the extent to which each was used in hybridization is indicated by the use of the numbers assigned in the sequence. The number of seedlings grown for each cross is indicated in italics under the female parent. Thus in the cross *P. alba*×*P. alba nivea* 67 seedlings were grown.

A. The white poplars.
   1. *Populus alba* ♀ ×2 (*67*); 3 (*8*); 4 (*34*); 6 (*22*); 7 (*16*).
   2. *P. alba nivea* ♂ ×1.
   3. *P. canescens* ♂ ×1.

B. The aspens.
   4. *P. adenopoda* ♂ ×1, 17.
   5. *P. grandidentata* ♂ ×10, 31, 32.
   6. *P. tremula* ♂ ×1, 8.
   7. *P. tremula Davidiana* ♂ ×1.
   8. *P. tremuloides* ♀ ×6 (*11*).

[20] At Hillsboro, N. H.
[21] At Albany, N. Y.
[22] At Syracuse, N. Y.
[23] At Rumford, Maine, and Bronx Park, New York City, respectively.
[24] See Bibliography, published in the Yearbook separate of this article.

C. The black poplars and cottonwoods.
9. *P. angulata* ♀ ×10 (*583*); 11 (*248*); 12 (*99*); 16 (*203*); 21 (*214*); 22 (*60*); 25 (*214*); 26 (*205*); 34 (*264*).
10. *P. balsamifera virginiana* ♀ ×5 (*178*); 10 (*138*); *11* (*18*); 12 (*189*); 16 (*208*); 21 (*183*); 22 (*7*); 25 (*216*); 26 (*245*); 34 (*705*). ♂×9, 10, 13, 15, 18, 19, 23, 31, 33.
11. Cottonwood (unidentified) ♂×9, 10, 13, 15, 18, 19, 31.
12. *P. caudina* ♂×9, 10, 13, 18, 26, 29, 30, 31, 32.
13. *P. charkowiensis* ♀ ×10 (*288*); 11 (*267*); 12 (*266*); 16 (*263*); 21 (*312*); 22 (*52*); 25 (*188*); 26 (*249*); 34 (*221*).
14. *P. Eugenei* clone ♂×17, 23.
15. *P. fremonti* ♀ ×10 (*7*); 11 (*9*); 16 (*108*); 21 (*194*); 25 (*217*); 26 (*69*); 34 (*125*).
16. *P. incrassata* ♂×9, 10, 13, 15, 18, 19, 29, 31, 32.
17. *P. nigra* ♀ ×17 (*6*); 14 (*49*); 17 (*184*); 20 (*44*); 27 (*217*); 28 (*377*); 32 (*2*); 34 (*200*).
18. *P. nigra baatanicorum vitrum* ♀ ×10 (*6*); 11 (*60*); 12 (*51*); 16 (*10*); 21 (*157*); 25 (*170*); 34 (*121*).
19. *P. nigra betulifolia* ♀ ×10 (*11*); 11 (*11*); 16 (*141*); 21 (*65*); 25 (*166*); 34 (*209*).
20. *P. nigra Italica* (clon Lombardy) ♂×17, 23.
21. *P. nigra plantierensis* ♂×9, 10, 13, 15, 18, 19, 26, 29, 31, 32, 33.
22. *P. robusta* clone ♂×9, 10, 13, 32.
23. *P. sargentii* ♀ ×10 (*72*); 14 (*50*); 20 (*25*); 23 (*35*); 26 (*149*); 27 (*309*); 28 (*51*); 32 (*14*); 34 (*233*).
24. *P. serotina* clone ♂×26.
25. *P. volga* clone ♂×9, 10, 13, 15, 18, 19, 26, 31, 32.

D. The balsam poplars, and the older hybrids strongly balsam in character.
26. *P. barolinensis* ♀ ×12 (*8*); 21 (*17*); 24 (*29*); 25(*62*); 26 (*31*); 34 (*27*). ♂×9, 10, 13, 15, 26, 23, 29, 31, 32, 33.
27. *P. berolinensis rossica* ♂×17, 23.
28. *P. laurifolia* ♂×17, 23, 33.
29. *P. maximowiczii* ♀ ×12 (*179*); 16 (*2*); 21 (*145*); *26* (*112*); 34 (*5*).
30. *P. petrowiskyana* ♀ ×12 (*25*).
31. *P. rasumowskyana* ♀ ×5 (*2*); 10 (*56*); 11 (*30*); 12 (*70*); 16 (*25*); 21 (*76*); 25 (*81*); 26 (*183*); 34 (*148*).
32. *P. simonii* ♀ ×5 (*32*); 12 (*99*); 16 (*75*) 21 (*176*); 22 (*1*); 25 (*155*); 26 (*189*); 34 (*44*). ♂×17, 23.
33. *P. tacamahacca candicans* clone Balm of Gilead ♀ ×10 (*6*); 21 (*40*); 26 (*82*); 28 (*6*).
34. *P. trichocarpa* ♂×9, 10, 13, 15, 17, 18, 19, 23, 26, 29, 31, 32.

Approximately 700 hybrid seedlings were originally selected for intensive study and evaluation, and of this number 69 are still under close observation. Descriptions have been published of 10 of these hybrids that appear particularly promising for use in reforestation.

Propagation of the new poplar hybrids has been entirely vegetative, by cuttings. Many of the hybrids have so far indicated greater growth vigor than any previously known poplar species or hybrids. Some have been practically immune to certain diseases, particularly *Melampsora* rust and *Fusicladium* twig disease. Selections have included frost-hardy types with good forest form that grow vigorously from cuttings. There is evidence that the wood of many of the fast-growing hybrids will be denser, and will produce somewhat longer fibers, than the aspens now used for pulpwood. Most of the original hybrids are growing in plantations (now 9 and 10 years old) and many have begun to bloom; some individuals flowered at the age of 7 years.

Foreign Agencies

Austria, Forstliche Bundes, Versuchsanstalt, Mariabrunn

1. Seed Origin

Considerable research has been carried out on climatic races and on the importance of the seed origin of forest trees. This work was started previous to 1900. The progress of the work has been reported in publications by Cieslar, Tschermak, and Oehm.

Canada, Petawawa Forest Experiment Station,[25] *Ontario*

3. Tree Breeding

Crosses between black spruce and Norway spruce, attempted in Canada in 1934, were unsuccessful. In 1936 *Populus canescens* was crossed with *P. grandidentata*, and *P. tremuloides* was crossed with *P. grandidentata*, in an effort to obtain a hybrid combining the wood characteristics required for match and veneer wood with resistance to heart rot.

C. Heimburger of this station reports that in 1932 he crossed red spruce with Norway spruce while working in New York State. Good seed was produced, and the seedlings are now being grown by the New York State College of Forestry.

Denmark, Royal Veterinary and Agricultural College, Copenhagen

3. Tree Breeding

In the spring of 1924, *Abies concolor lowiana* (Pacific white fir) was successfully crossed with *A. grandis* (lowland white fir), and the hybrids are under observation at the present time. In 1929 *Juglans sieboldiana* (Japanese walnut) was successfully crossed with *J. cinerea* (butternut). Reciprocal crosses have been made between *Larix leptolepis* (Japanese larch) and *L. decidua* (European larch). Rather extensive self-pollinations have been made by covering portions of large trees, or entire smaller trees, with closely woven canvas. A tree of *Chamaecyparis* sp. was selfed by covering its top. A larch (7.1 m tall) thought to be a hybrid between *Larix gmelini* and *L. leptolepis* was tented and self-fertilized. A small Japanese larch was also selfed by potting and transferring it to a greenhouse.

Germany, Botanisches Institut der Forstlichen Hochschule, Eberswalde

1. Seed Origin

Studies are now under way on climatic races of *Pinus sylvestris* (Scotch pine) and *Pseudotsuga taxifolia* (Douglas fir). Progenies of Douglas fir from 19 different seed sources are growing in the vicinity of Eberswalde. Particular emphasis has been placed upon the possible selection of Douglas fir races that are highly resistant to *Rhabdocline* leaf disease. Results to date indicate that in general the American coastal forms, although not entirely immune, are sufficiently resistant to warrant further use in forest planting; that the mountain forms are slower growing, more susceptible to the disease, and cannot be recommended; and that certain types should be discontinued entirely.

3. Tree Breeding

Reciprocal crosses between *Pinus montana* and *P. sylvestris* have apparently been unsuccessful. Since natural hybrids between these species have been reported, it is possible that the negative results may have been due to lack of "crossibility" of the strains that were used.

Germany, Forstbotanisches Institut, Technischen Hochschule, Dresden (Forstliche Abteilung Tharandt)

1. Seed Origin

Seed origin investigations of a large number of forest trees, including pine, spruce, larch, oak, beech, aspen, alder, ash, and maple, are under way at this station. In addition to the above the following species of most diverse seed origin are also being tested in experimental plots: *Pseudotsuga taxifolia, Betula verrucosa, Pinus murrayana, Abies cilicica, Pinus armeniaca, P. peuce, Picea engelmannii, P. sitchensis, Chamaecyparis lawsoniana.*

Great Britain, Forestry Commission of Great Britain, Research Division[26]

1. Seed Origin

Investigations on climatic races of *Pseudotsuga taxifolia*, two species each of *Larix*, *Picea*, and *Quercus*, and four species of *Pinus* are under way. This work was started in 1925 and it is too early to draw any conclusions. The investigations will include a study of growth and form, frost-hardiness, and resistance to fungus and insect attacks.

[25] At Petawawa, Ontario.
[26] At London.

Switzerland, Eidgenössische Zentralanstalt für das Forstliche Versuchswesen, Zürich

1. Seed Origin

Studies on site races, form races, and so forth, were started in 1898 with two species each of *Pinus* and *Quercus*, one species each of *Picea*, *Abies*, *Larix*, *Fagus*, *Acer*, and other important tree species. These studies include the influence of geographical location, latitude, altitude, soil, precipitation, form, age, and position of the parent tree in the stand. Results indicate that the following characteristics are inherited: Color and size of needles and leaves, crown form, stem form, increment, growth periods, and resistance to frost, heat, light, snow, fungi, and insects.

These investigations are of great importance since they are to be applied to protection forests in many of the regions where natural regeneration is practiced. Results have been published by Engler, Nägeli, and Burger.

BIBLIOGRAPHY

A bibliography for this article, including over 300 references related to forest tree breeding, will be published in the 1937 Yearbook Separate containing the text of the article.

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